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Evaluation of the Disposal of Flue Gas Desulfurization Wastes in Coal Mines and the Ocean: Mine Disposal Demonstration Tests

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AN EVALUATION OF THE DISPOSAL OF FLUE GAS DESULFURIZATION WASTES IN COAL MINES AND THE OCEAN:

MINE DISPOSAL DEMONSTRATION TESTS

By

Chakra J. Santhanam, James R. Valentine and Armand A. Balasco

Arthur D. Little, Inc.
20 Acorn Park
Cambridge, Massachusetts 02140

Contract No. 68-03-2334

EPA Project Officer: Julian W. Jones

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

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16. ABSTRACT

The report gives results of an assessment of a full-scale flue gas desulfurization (FGD) waste disposal operation at the Baukol-Noonan Mine near Center, ND. FGD wastes from the alkaline fly ash scrubbing system are disposed of in the mine area in V-notches (Vees) and in the pit bottoms. A program of evaluating this disposal operation consisted of placement of monitoring wells, physical and chemical sampling and analysis of groundwater and wastes, and environmental and engineering cost assessment. The primary environmental effect potential of FGD waste disposal in mining may be in the generation of leachates showing increased concentrations of sulfate, sodium, magnesium, and (to a lesser extent) calcium. However, such FGD waste disposal when properly practiced reduces potential effects of fly-ash-related leachate generation. Placement of the FGD wastes in Vees appears preferable to pit bottom disposal. The capital cost for mine disposal of FGD wastes (including thickening and filtration prior to disposal) from a 438-MW (net) lignite-fired boiler is estimated at about $10.85 million: the annual operating cost is estimated at about $10.70 per ton.

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a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Leaching	Pollution Control	13B	
Flue Gases	Fly Ash	Stationary Sources	21B	
Desulfurization	Cost Analysis	In-mine Disposal	07A, 07D	14A
Ground Water	Testing		08H	14B
Waste Disposal				
Mines (Excavations)			08I	

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This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

This report presents an assessment of a full-scale FGD mine disposal operation. It covers the work performed in the last phase of a three-phase project conducted by Arthur D. little for EPA under Contract No. 68-03-2334. It also includes results from EPA Grant No. R805459 to the University of North Dakota.

The mine disposal operation assessed was at the Baukol-Noonan Mine near Center, ND. FGD wastes from the alkaline fly ash scrubbing system are disposed of in the mine area in vee-notches and in the pit bottoms. A program of evaluating this disposal operation consisted of placement of monitoring wells, physical and chemical sampling and analysis of groundwater and wastes and environmental and engineering cost assessment.

The primary environmental effect potential of FGD waste disposal in mining may be in the generation of leachates showing increased concentrations of sulfate, sodium, magnesium and to a lesser extent calcium. However, such FGD waste disposal when properly practiced reduces potential effects of fly ash related leachate generation. Placement of the FGD wastes in vee-notch appears preferable to pit bottom disposal.

The capital cost for mine disposal of FGD wastes (including thickening and filtration prior to disposal) from a 438 Mw (net) lignite fired boiler is estimated at about $10.85 million: the annual operating cost is estimated at about $10.70 per ton.

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ARTHUR D. LITTLE, INC.

Principal Investigators

Chakra J. Santhanam - Project Manager
James R. Valentine
Armand A. Balasco

Participating Staff

Charles B. Cooper
Itamar Bodek

UNIVERSITY OF NORTH DAKOTA

Oscar E. Manz - Project Manager
David J. Hassett
Harvey A. Gullicks

NORTH DAKOTA GEOLOGICAL SURVEY

Gerald H. Groenwold

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In particular, we wish to acknowledge Julian W. Jones, the EPA Project Officer, for his guidance throughout the course of this work and his invaluable assistance in the preparation of this report.

CONVERSION FACTORS

English/American Units	Metric Equivalent
Length:	
1 inch	2.540 centimeters
1 foot	0.3048 meters
1 fathom	1.829 meters
1 mile (statute)	1.609 kilometers
1 mile (nautical)	1.852 kilometers
Area:	
1 square foot	0.0929 square meters
1 acre	4,047 square meters
Volume:	
1 cubic foot	28.316 liters
1 cubic yard	0.7641 cubic meters
1 gallon	3.785 liters
Weight/Mass:	
1 pound	0.4536 kilograms
1 ton (short)	0.9072 metric tons
Pressure:	
1 pound per square inch	0.07031 kilograms per square centimeter
Concentration:	
1 part per million (weight)	1 milligram per liter
Speed:	
1 knot	1.853 kilometers per hour
Energy/Power:	
1 British Thermal Unit	1,054.8 joules
1 megawatt	3.600×10^9 joules per hour
Temperature Change:	
1 degree Fahrenheit	5/9 degree Centrigrade

1.0 EXECUTIVE SUMMARY

1.1 Program Purpose and Scope

This is the last report in a project undertaken under EPA's Water and Wastes Program. The project consisted of investigations by Arthur D. Little, Inc., (ADL), the New England Aquarium (NEA), and the University of North Dakota (UND), regarding the feasibility of the disposal of Flue Gas Cleaning (FGC) wastes in mines and at sea. In this program, the FGC wastes studies were wastes from non-recovery Flue Gas Desulfurization (FGD) systems and mixtures of FGD wastes and coal ash.

Two earlier reports described the first two phrases of this project:

- The report on the first phase presented a preliminary assessment performed by Arthur D. Little of the environmental, technical, regulatory and economic aspects of projected mine and at-sea disposal operations.(1)

- The report on the second phase presents a refinement of the preliminary assessment based upon additional evaluation of selected impact issues identified in the initial effort as requiring further study.(2)

The objectives of the third phase of this project described in this Report consisted of monitoring a full-scale FGD mine disposal operation at the Baukol-Noonan mine near Center, North Dakota. The purpose was to evaluate the environmental effects of full-scale FGD waste disposal in mines and develop capital and operating costs of such disposal operations.

This is the third (and final report) on the mine disposal and assesses the field demonstration of a mine disposal operation. As stated above, the mine disposal operation selected for this assessment is the one at Baukol-Noonan Mine near Center, North Dakota. The mine supplies coal to and receives waste from the Milton R. Young Station of the Minnkota Power Cooperative.

1.2 Demonstration Project Description

The field studies were carried out at the Center Mine operated by Baukol-Noonan using FGC wastes from the Milton R. Young Station of Minnkota Power Cooperative near Center, ND. There are two boilers, Units NO. 1 and 2, at this power plant; the latter a 438 Mw (net) cyclone fired boiler being the one with FGD system. The FGD system uses alkaline fly ash from both boilers as the principal source of alkali for removal of sulfur oxides.

The FGD waste as wet filter cake was transported to the mine area in rear dump trucks to facilitate removal during cold weather 3 to 4 tons of boiler slag are placed on the bottom of the trucks and serve as liner for 24-28 tons of FGD wastes. The FGD wastes were placed in V-notch and pit bottom locations.

The above waste disposal scheme began in 1977 but was constantly plagued with problems. Consequently the plant decided to retire the thickener and vacuum filter and direct the scrubber effluent directly to settling ponds to achieve dewatering. This interim pond/mine disposal scheme has been in operation since November 1981.

The environmental assessment part of this project focusses on the original operation. However, capital and operating cost estimates were made for both the original and current process schemes.

The approach for environmental and engineering/cost assessment involved carrying out a series of sequential data gathering and assessment steps designed to afford an appropriate data base and to provide general guidance in its assessment.

- Geological and geohydrological data on the site and environs are gathered during the site development activities which included placement of water wells and piezometers.

- Data on the composition and characteristics of waters, wastes and geologic strata of interest are obtained during the sampling and analysis activities.

- Using the site data, data from the laboratory tests, as well as the existing background on FGC wastes and disposal effects, cause/effect relationships are developed, and tested, to fit the measured site data.

- The cause/effect hypotheses are used to develop projects of the generic implications of effects observed at the test site to other similar FGC waste disposal scenarios.

Attached Figure 1-1 provides a sketch of the disposal area and location of groundwater and leachate wells installed after sludge disposal in V-notches and pit bottoms.

The environmental and economic assessment program were carried out principally through the coordinated efforts of two groups, one from Arthur D. Little, Inc., and the other from the University of North Dakota (UND). In addition, officials and staff from both the power company (Minnkota Power Cooperative, Inc.) and the mine (Baukol-Noonan, Inc.) provided valuable assistance and cooperation.

The actual sampling and analysis as well as the day-to-day coordination of the test program has been carried out by the University of North Dakota (UND) under EPA Grant No. R805459. Arthur D. Little provided overall review of the program and evaluated the data and information generated.

1.3 Environmental Assessment

Table 1.1 provides an overview of some of the data to illustrate the discussion of environmental effects. Overall, it appears that placement of FGD wastes from alkaline fly ash-FGD systems will result in generation of

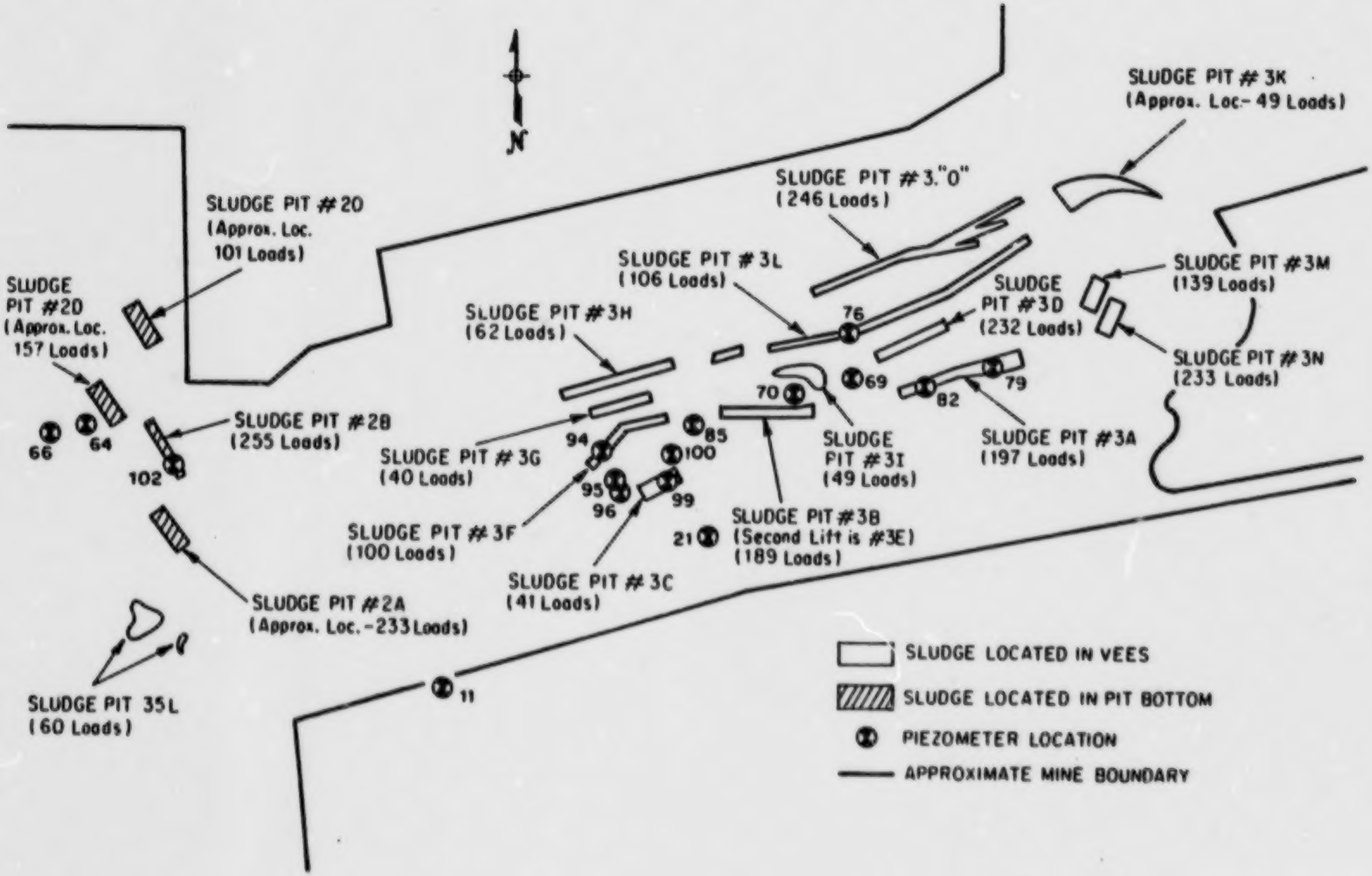
N
SLUDGE PIT #20
(Approx. Loc.
101 Loads)
SLUDGE
PIT #2D
(Approx. Loc.
157 Loads)
66
64
102
SLUDGE PIT #2B
(255 Loads)
SLUDGE PIT #2A
(Approx. Loc. -233 Loads)
SLUDGE PIT 35L
(60 Loads)
11
SLUDGE PIT #3H
(62 Loads)
SLUDGE PIT #3G
(40 Loads)
SLUDGE PIT #3F
(100 Loads)
SLUDGE PIT #3C
(41 Loads)
94
95
96
99
100
85
21
SLUDGE PIT #3L
(106 Loads)
SLUDGE PIT #3."O"
(246 Loads)
76
70
69
SLUDGE
PIT #3I
(49 Loads)
SLUDGE PIT #3B
(Second Lift is #3E)
(189 Loads)
SLUDGE
PIT #3D
(232 Loads)
82
79
SLUDGE PIT #3A
(197 Loads)
SLUDGE PIT #3K
(Approx. Loc.- 49 Loads)
SLUDGE PIT #3M
(139 Loads)
SLUDGE PIT #3N
(233 Loads)
SLUDGE LOCATED IN VEES
SLUDGE LOCATED IN PIT BOTTOM
PIEZOMETER LOCATION
APPROXIMATE MINE BOUNDARY

FIGURE 1-1 LOCATION OF GROUNDWATER AND LEACHATE WELLS INSTALLED AFTER SLUDGE DISPOSAL IN VEES AND DRY PITS.

TABLE 1.1

PARAMETERS OF INTEREST FOR WELLS SHOWING EVIDENCE OF FGD-RELATED LEACHATE

Well No.	Waste/ Well Locations[1,3,5]	Chemical Analysis Data[2]					Approximate Dates[3]	
		Date Sampled	Analyte Concentration (mg/L)					
			Sulfate	Sodium	Magnesium	Calcium	Waste Disposal	Over-burden Return
99	"Vee"-3C/ below waste	3/27/80	4111	960	530	215.5	10/78	5/79
		6/09/80	3811	1050	408	393		
		9/09/80	3500	776	457	331		
94	"Vee"-3F/ offset from waste	3/27/80	4917	900	615	195.3	11/78	5/79
		6/09/80	3572	493	262	307		
		9/09/80	4980	730	596	404		
79	"Vee"-3A/ below waste	6/09/80	1922	331	358	215	9/78	4/79
		9/09/80	2891	567	421	416		
102	pit bottom - 2B/below and offset from waste	3/27/80	1465	823	49.5	65.8	6/78	4/79
		6/09/80	4343	1845	105	186		
		9/09/80	5108	2200	151	560		
Data for Related Groundwater Wells -								
76	"Vee"-3L/ below waste?	6/09/80	222	322	34	65	3/79	5/79
		9/09/80	148	377	30	58		
Average of "spoils wells"[4]		1978-79	1455	361	232	348		
Average of "below Hagel" wells[4]		1978-79	1217	568	80.4	153		
Average of "Hagel Bed" wells[4]		1978-79	668	297	74.3	105		

[1] from Figure 7-2

[2] from Table 7-7

[3] from Table 6-3

[4] from Table 7-5

[5] from Table 7-6 and Figure 7-3

liquors and leachates which show increased concentrations of sulfate, sodium, magnesium, and to some extent, calcium. Of these the sulfate (and consequently, total dissolved solids) will be substantially above drinking water limits (250 mg/L and 10,000 mg/L respectively). At the same time, the results indicate that for FGD wastes trace elements in leachates are likely to be within the allowable range for drinking water.

The concentration of sulfate and magnesium found in the well samples obtained are substantially lower than the compositions of undiluted FGD waste porewater. Sodium concentrations are also lower than porewater except in the pit bottom location where higher sodium and correspondingly lower magnesium concentrations may be the results of ion exchange processes. Calcium appears to be under solubility control by sulfate. These data suggest two possible scenarios related to the FGD waste leaching: either the groundwater even in close proximity to the waste is a mixture of waste leachate and other infiltrating groundwater which bypassed or "channeled" through the waste; or the contact of infiltrating groundwater does not provide as efficient an extraction of solubles as predicted by the laboratory leaching column tests. While the cause cannot be ascertained with certainty, for vee-notch disposal the net effect is the same, namely that such disposal may not result in the appearance of a "plug" of full-strength FGD-waste purewater in the groundwater. The data for the pit bottom placement location suggest that the leachate concentration (i.e. the fraction of leachate) is higher than for vee-notch.

The data indicate that the major impact on groundwater from the FGD wastes generated at the Milton R. Young plant will stem from the high concentrations of sulfate, and those portions of other major species which contribute to the dissolved solids. These TDS contributors are present in the wastes as soluble species readily available for leaching.

The UND investigation outside the scope of Arthur D. Little efforts also focused on characterization and assessment of the environmental effects relating to the disposal of alkaline fly ash itself. This phase of their investigation indicates that, in the absence of a working FGD system, the alkaline ash was disposed in mine in the same manner as the FGD wastes. In contrast to FGD wastes, alkaline fly ash appears to have a rather significant potential to impact the environment particularly in trace metal mobility. Although the primary purpose of fly-ash type FGD systems is to reduce atmospheric SO_2 contamination, the results indicate that a potential secondary benefit of this method of FGD is the conversion of fly ash from a form that can cause groundwater to exhibit toxicity (because of high arsenic and selenium levels) to a waste form that causes increased sulfate concentrations but generally no significant increases in the more toxic elements.

Placement and disposal of FGD waste in mined areas may offer an effective means of disposing of this waste, providing that the waste is placed in favorable locations in the minded area and provided that the disposal practice is accomplished with appropriate consideration for the geohydrological nature of the site.

Placement of these wastes in vee-notch settings appears to be highly preferable to pit bottom disposal in most areas. Vee-notch areas are commonly above the postmining watertable, and thus offer much less opportunity for the dissolution and leaching of soluble salts present in these waste products.

1.4 Engineering/Cost Assessment

The original and current waste disposal schemes are shown in Figures 1-2 and 1-3. The original waste handling/processing/disposal system which was in operation for about four years at the Milton R. Young plant consisted of thickening and vacuum filtering the fly ash/FGD scrubber

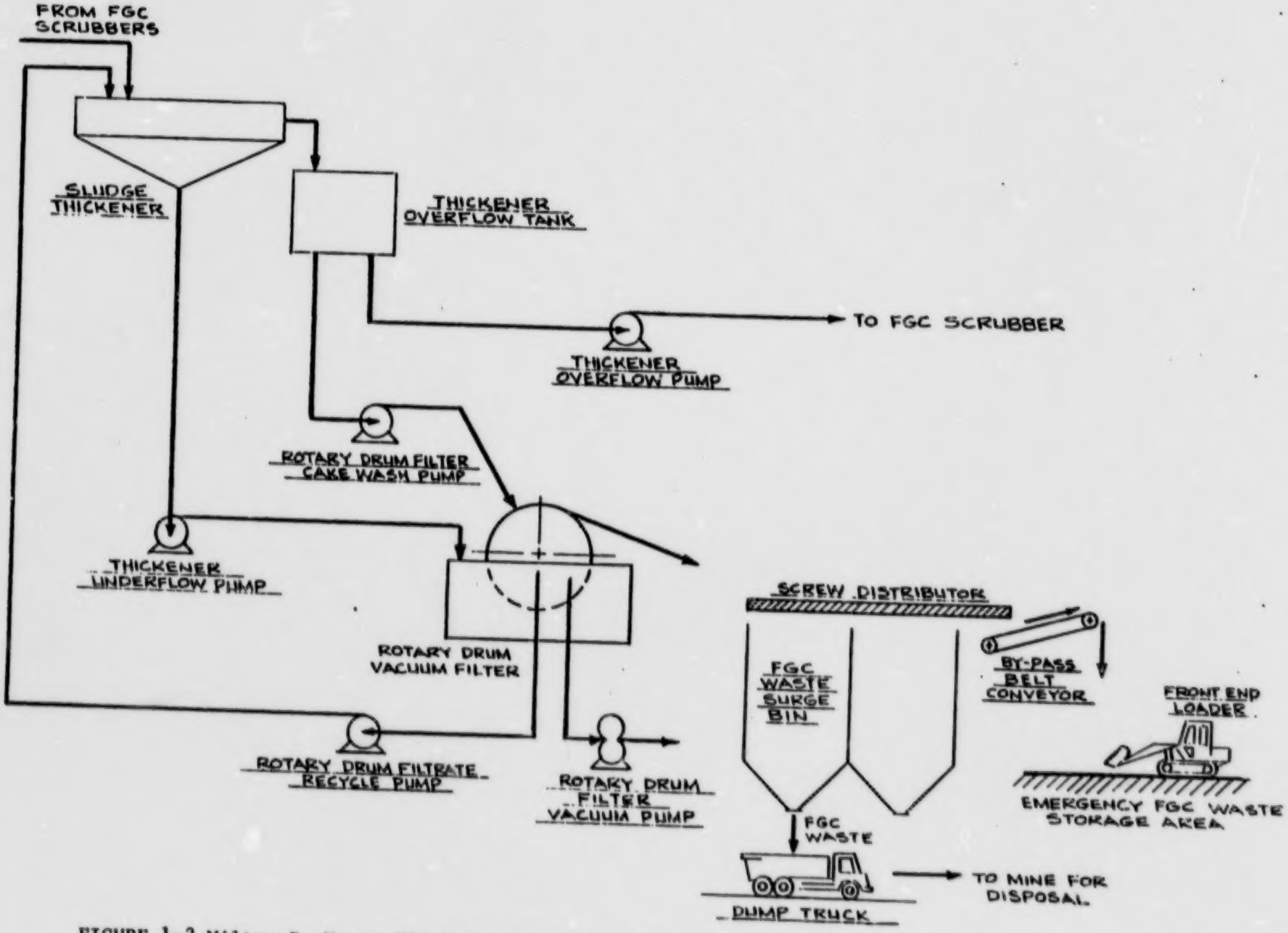
FROM FGC SCRUBBERS
SLUDGE THICKENER
THICKENER OVERFLOW TANK
TO FGC SCRUBBER
THICKENER OVERFLOW PUMP
ROTARY DRUM FILTER CAKE WASH PUMP
THICKENER UNDERFLOW PUMP
ROTARY DRUM VACUUM FILTER
ROTARY DRUM FILTRATE RECYCLE PUMP
ROTARY DRUM FILTER VACUUM PUMP
SCREW DISTRIBUTOR
FGC WASTE SURGE BIN
BY-PASS BELT CONVEYOR
FRONT END LOADER
EMERGENCY FGC WASTE STORAGE AREA
FGC WASTE
DUMP TRUCK
TO MINE FOR DISPOSAL

FIGURE 1-2 Milton R. Young FGC Waste Processing/Interim Storage/Transport Schematic Flow Diagram (Original Scheme as of 1977-1978).

Reference: (11)

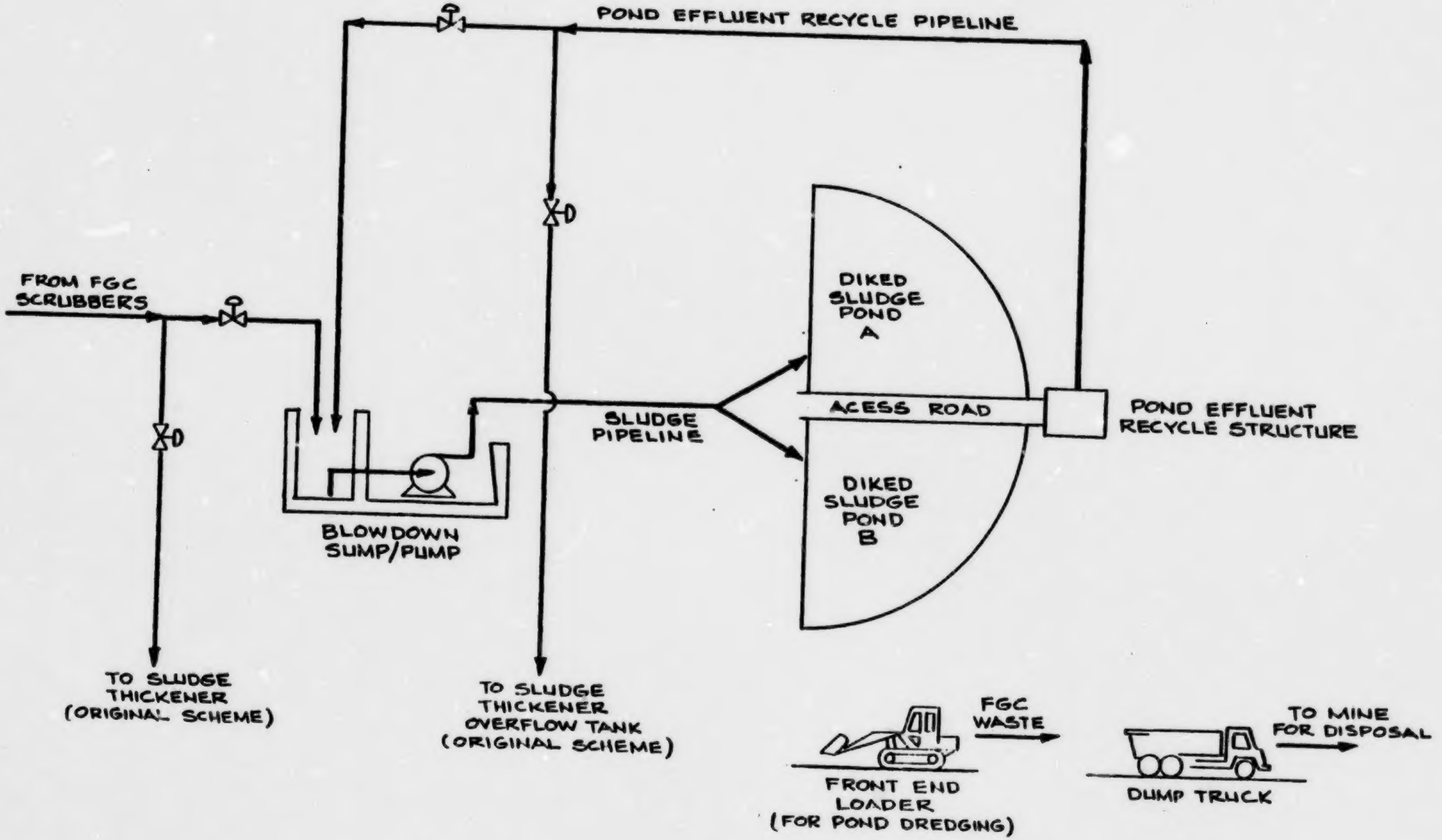
POND EFFLUENT RECYCLE PIPELINE
FROM FGC SCRUBBERS
DIKED SLUDGE POND A
ACESS ROAD
DIKED SLUDGE POND B
SLUDGE PIPELINE
POND EFFLUENT RECYCLE STRUCTURE
BLOWDOWN SUMP/PUMP
TO SLUDGE THICKENER (ORIGINAL SCHEME)
TO SLUDGE THICKENER OVERFLOW TANK (ORIGINAL SCHEME)
FGC WASTE
FRONT END LOADER (FOR POND DREDGING)
TO MINE FOR DISPOSAL
DUMP TRUCK

Figure 1-3 Milton R. Young FGC Waste Handling/Interim Storage/Transport Schematic Flow Diagram (Process as of 1980-1981)

effluents from about 15 wt% solids to about 65 wt% solids. From the vacuum filter, the 65 wt% fly ash/FGD waste was directed by belt conveyor to one of two surge bins. The surge bins acted as temporary storage for the waste until it was loaded onto 35-ton coal haul trucks. These trucks transported the waste to the Baukol-Noonan, Inc., Center Mine which is located about five miles from the plant. At the mine, the waste was deposited as a relatively dry soil-like material in either: (a) the pit bottom prior to the return of overburden; (b) the spoil banks (vee-notches) before rough contouring.

The current scheme shown in Figure 1-3 eliminates thickening and filtration operations. Instead the scrubber effluent is directly ponded. Table 1.2 provides a summary of capital costs while Table 1.3 and 1.4 provide the basis for and summary of annual operating costs for both original and current schemes.

Mine disposal appears to be among the lowest cost methods of FGD waste disposal. In generic terms, mine disposal may be 20-25% less expensive than disposal in managed fill due to lower land and mobile equipment costs; additionally reclamation is a normal part of mine operation with or without waste disposal and hence not charged to disposal operation (since it is required in any case).

TABLE 1.2

CAPITAL COSTS - FGD WASTE DISPOSAL

Basis:
1. Operation of Baukol-Noonan Mine Disposal
2. All Costs in 1981 Dollars
3. Unit No. 2 (438 Mw net, cyclone fired) Uses North Dakota lignite and has alkaline fly ash based FGC System

No.	Detail	Original Scheme	Capital Cost $1000	Current Scheme	Capital Cost $1000
1.	Handling, processing and storage	Thickeners with auxilaries Rotary vacuum filter with auxiliaries Surge bin By-pass converger	10,000	Blowdown pump and auxiliaries Sewage Pond Pipeline and access road Effluent recycle lime Dredging equipment	4,500
2.	Transportation Placement and disposal	Truck, loader Dozers and graders	850		850
3.	Total Cost		10,850		5,350

TABLE 1.3

WASTE DISPOSAL ENGINEERING OPERATING BASIS

MILTON R. YOUNG (UNIT 2)

Boiler	
Capacity (Mw):	476
Annual Load Factor (%):	90
Heat Rate (Btu/kwh):	10,000
Fly Ash/Botom Ash Ratio:	35/65
Coal	
HHV (Btu/lb):	6,422
Sulfur Content (%):	.64
Ash Content (%):	9.74
Emission Control	
SO_2 Removal (%):	60
Particulate Removal (%):	99+
Wastes Generated	
Fly Ash[a] (tons/yr):	157,300
FGD Sludge (tons/yr):	58,475
Total FGD Waste (tons/yr):	215,775 (dry basis)
Total FGD Waste (tons/yr):	332,000 (wet basis)

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[a] Includes fly ash from Unit 1 and Unit 2, since fly ash from Unit 1 is used in alkaline fly ash scrubbing operation. Capacity of Unit 1 is 265 Mw.

Reference: (11) and Arthur D. Little Estimate

TABLE 1.4

ANNUAL OPERATING COST SUMMARY
(1981 Dollars)

	($1000) Original Disposal Scheme[a]	($1000) Current Disposal Scheme[b]
DIRECT COSTS		
• Operating/Supervisory Labor	$417.2	$495.8
• Maintenance (Labor and Materials)	354.0	214.0
• Utilities		
- Water (@ $.01/k gal)	.3	.3
- Electricity (@ $.03/kwh)	156.0	54.0
- Diesel Fuel (@ $.95/gal)	255.7	332.4
INDIRECT COSTS		
• Plant Overhead (@ 50% Direct Costs minus Electricity)	513.6	521.3
• Administrative Overhead (@ 10% Total Labor Cost)	59.4	60.3
• Capital Charges (@ 16.5% of Total Capital Cost)	1798.5	891.0
TOTAL ANNUAL OPERATING COST		
• ($1000 $/year)	$3554.7	$2570.1
• ($/ton)	$ 10.70	$ 7.75

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[a] Thickening/Vacuum Filtration/Mine Disposal Scheme - Milton R. Young (Unit 2)

[b] Interim Ponding/Mine Disposal Scheme - Milton R. Young (Unit 2)

Reference: (11) and Arthur D. Little Estimates

2.0 INTRODUCTION

2.1 Overview

As the nation turns to coal as the primary fossil fuel, coal utilization in industrial and utility boilers is expected to increase dramatically. Consequently, generation of coal ash (fly ash and bottom ash), and flue gas desulfurization (FGD) wastes, which together can be referred to as flue gas cleaning (FGC) wastes, is expected to increase dramatically over the next 20 years. Most of the FGC wastes generated will be disposed of rather than utilized. These wastes represent potential sources of environmental pollution unless proper disposal technology is employed. Continuing research and development efforts in recent years sponsored by the Environmental Protection Agency (EPA), the Department of Energy (DOE), Tennessee Valley Authority (TVA), Electric Power Research Institute (EPRI), a number of utilities, and others have provided substantail information on environmentally sound disposal techniques and the economic impact of such disposal.

Since 1974, the EPA has had an ongoing waste and water program to evaluate, develop, demonstrate, and recommend environmentally acceptable cost-effective technology for FGC waste disposal utilization and power plant water recycle/treatment/reuse. One of the elements of this effort has been the program consisting of investigations by Arthur D. Little, Inc. (ADL), the New England Aquarium (NEA), and the University of North Dakota (UND), regarding the feasibility of the disposal of Flue Gas Cleaning (FGC) wastes in mines and at sea. In this program, the FGC wastes studies were wastes from non-recovery Flue Gas Desulfurization (FGD) systems and mixtures of FGD wastes and coal ash.

The report of the first phase of the program presented a preliminary assessment performed by Arthur D. Little of the environmental, technical, regulatory and economic aspects of projected mine and at-sea disposal operations. The purpose of the initial assessment was to evaluate the overall viability and acceptability of disposal and to determine the most promising disposal options and practices.(1)

The report on the second phase of the program presents a refinement of the preliminary assessment based upon additional evaluation of selected impact issues identified in the initial effort as requiring further study.(2) The purpose of this refinement, therefore, was to acquire additional information necessary to have a more complete understanding of the fate and effects of FGC wastes in coal mine and ocean environments, and a more accurate estimate of the cost of selected disposal operations.

This is the third (and final) report on mine disposal and assesses the field demonstration of a surface mine disposal operation. The mine disposal operation selected for this assessment is at Baukol-Noonan Mine near Center, North Dakota. The mine supplies coal to (and receives waste from) the Milton R. Young Station of the Minnkota Power Cooperative.

This Third Report is intended to primarily focus on the specific site assessed. Hence, the reader is advised to consider the three reports as complementary to each other. For this reason, only a brief overview of the results of the first two are presented to provide some perspective.

2.2 Scope and Organization of This Report

Scope

Mine disposal demonstration testing in Phase III of this project involved monitoring a portion of the full-scale FGD sludge disposal operation at the Baukol-Noonan Mine in Center, North Dakota. The actual sampling and analytical work and day-to-day coordination of the testing was performed by the University of North Dakota (UND) under EPA Grant No. R805459. The testing program under the grant to UND ran for a period of 24 months, from 1977 to 1980. It focussed on the characterization of the physical and chemical properties of the sludge, both prior to and following disposal, and on monitoring of groundwater quality and analysis of geochemical effects to determine pollutant mobility and impacts.

Arthur D. Little's (ADL) effort under this program and EPA Contract No. 68-03-2334 was to provide overall supervision and coordination of the UND test program at the Baukol-Noonan Mine. Specifically, Arthur D. Little:

- assisted in the formulation of the conceptual test program plan and reviewed the detailed work plan (prepared by UND under EPA Grant No. R805459);
- reviewed and advised with respect to appropriate sampling and analytical techniques;
- reviewed the data and evaluated the results of the test program;
- collected and presented data on the actual costs incurred in implementing and operating the mine disposal system; and
- assessed the results of the UND test program and incorporated these in the final report.

Organization of This Report

This report consists of eight chapters and appendices as follows:

- Chapter 1. Executive Summary. Describes the issues addressed in this, the third and final assessment on mine disposal under this project, the findings and conclusions and recommendations.
- Chaper 2. Introduction.
- Chapter 3. Briefly outlines the results of prior effort under Phase I and Phase II of this project.
- Chapter 4. Description of Test Site. This chapter provides an overview on the Test Site at Baukol-Noonan Mine.
- Chapter 5. Project Description. Provides an overview on the project approach to environment assessment and the project approach to engineering/cost assessment.
- Chapter 6. Summary of Project Activities. Provides an overview on data base gathered for environmental assessment and cost assessment.

- Chapter 7. Environmental Assessment. Describes the approach used and findings developed on environmental effects.

- Chapter 8. Engineering/Cost Assessment Provides details on the engineering of the FGD waste handling disposal practice at Baukol-Noonan Mine and associated costs.

- Appendix A. Provides overall data on the power plant and the FGD system.

- Appendix B. Provides summary data on site development and geohydrology..

- Appendix C. Provides summary data on chemical sampling and analysis.

- Appendix D. Provides summary data on physical testing of soils and wastes.

- Appendix E. Provides the text of the paper produced under the EPA grant by the University of North Dakota.

3.0 DISCUSSION OF PRIOR WORK

3.1 Overview on Mine Disposal Practice

A disposal method for FGD wastes that is receiving increased attention is mine disposal. It appears that surface coal mines and underground room and pillar mines for coal, limestone or lead/zinc ores offer particular potential(1). Of the four categories of mines noted above, coal mines, and in particular surface area coal mines appear to be the most likely candidates for waste disposal. Coal mines offer the greatest capacity for disposal, and they are frequently tied directly to power plants. In fact, some new coal-fired power plants are "mine-mouth" (located adjacent to the mine, or within a few miles). Since the quantity (volume) of FGC wastes produced is considerably less than the amount of coal burned, such mines usually would have the capacity for disposal throughout the life of the power plant.

In general, inactive surface mines are considerably less promising than active mines for FGD waste disposal. Unreclaimed surface mines can be used for disposal of wastes between remaining spoil banks, and these may offer suitable sites for disposal. However, because of recent surface mine reclamation legislation, the number of unreclaimed sites and total capacity for wastes available in the future will be limited.

In active surface mines, three are basically three options for the placement of FGD wastes:

- In the working pit, following coal extraction and prior to return of overburden;
- In the spoil banks, after return of overburden but prior to reclamation; and
- Mixed with or sandwiched between layers of overburden.

In any disposal operation in an active mine, though, the general overriding consideration is that disposal should cause minimal disruption of mining or reclamation activities. This provides a number of constraints on the disposal system.

a. First, the amount (volume) of sludge disposed of in any surface mine should not greatly exceed the amount of coal removed. The objectives of strip mine reclamation include returning the mined terrain to topographic configurations similar to original terrains. Also, returning significantly more waste to a mine than the coal extracted could slow down the mining and reclamation activities. In most cases, this does not really represent a constraint, since the wastes returned to the mine will usually be only those resulting from the coal removed. The amount of FGD waste generated from the combustion of coal will be considerably less than the quantity (weight or volume) of coal removed. Depending upon the type of coal, FGC system, and emission standards to be met, the volume of total waste (ash plus calcium-sulfur compounds) will range from less than 10% of the coal burned to slightly over 50%. With Western coals, which are relatively low in sulfur, less than 20% is the rule. With higher sulfur Eastern and Interior coals, the total amount of wastes will typically run 30% or more.

b. Second, the physical condition (consistency) of the wastes must be amenable to ease of handling, transport, and placement using earth-moving equipment with minimal potential impact on the mining operations. For pit-bottom disposal this means that wastes at the time of placement or immediately thereafter should have as a minimum the consistency of a soil-like material with little or no liquefaction potential.

A slurry-like material or a waste with a tendency to flow either when placed or when overburden is dumped on top would present significant operational problems or unacceptably high costs for containment measures. A little more leeway exists for disposal in V-notches (between spoil banks); however, here again, soil-like materials or relatively cohesive materials that are relatively easily handled and transported will result in the least cost and minimal disruption of reclamation activities. At the least, the wastes must be well filtered (55% solids or higher), and may need to be admixed with dry fly ash, or stabilized.

c. Finally, minimal use should be made of existing mine equipment for transport and placement of the wastes at the mine. Dedicated equipment is preferred and, in most cases, mandatory. In almost all scenarios, waste is most easily placed by truck dumping. The use of coal trucks for this purpose could lead to unacceptable delays in coal mining operations due to the additional time for waste loading and discharging (and possible cleaning operations). Furthermore, many large mines use large bottom-dump trucks for coal haulage. These are designed to carry as much as 150 tons of coal and are usually constructed of aluminum. Not only can the water corrode the aluminum, but the bottom dumping of wastes would be impractical. These trucks are not designed for ease of maneuvering, and operating them (or any other equipment) on a freshly dumped layer of waste would be difficult at best. The type of truck used for transport and placement will greatly affect the quantity of waste that can easily be disposed of.

At present there are two commercial operations involving mine disposal of FGD wastes in surface coal mines - one at Texas Utilities' Martin Lake Station and the other at Square Butte's Milton R. Young Station (North Dakota). Both stations fire lignite and involve returning combined fly ash and calcium-sulfur compounds from SO_2 removal to the respective mines. The operation at the Baukol-Noonan mine which supplies coal to the Milton R. Young Power Station employs both pit-bottom and spoil bank disposal.

Mine disposal of FGD wastes can potentially be employed for subsidence control, acid mine drainage neutralization, reclamation of mine areas or as soil amendments for tailings disposal from mining operation. Thus, there could be subsidiary benefits from this type of disposal.

Mine disposal of coal ash is also practiced in some cases. (Baukol-Noonan Mine mentioned above, Jim Bridger Plant of Pacific Power & Light, and Cheswick Plant of Duquesne Light are examples). Mine disposal of coal ash is also anticipated to grow in the future.

3.2 Initial Assessment - 1977

The first assessment report (1) under this project was published in 1977. A brief review of the results of their effort is presented below.

There are over 15,000 mines in the United States today which together produce over one-half billion tons of coal and 2.5 billion tons of metallic and nonmetallic minerals. About one-third of these mines individually produce over 100,000 tons/year.

To focus on the most promising alternatives for coal ash and FGD waste disposal, mines were broadly grouped according to region, mineral mined, mine capacity, and method of mining; and each group has been screened with regard to overall technical feasibility.

Based upon the screening of the mining industry, the methods of disposal available, and the operational constraints in disposal, the following general mine options were selected for assessment.

Mineral	Mining Method	Region	Disposal Method	Sludge Form
Coal	Surface	Eastern, Interior and Western	Truck Dumping into Pit	Moist Filter Cake
Coal	Underground Room and Pillar	Eastern, Interior	Hydraulic Stowing	Thickened Slurry
	Longwall	Eastern, Interior	Pneumatic Stowing	Moist Filter Cake
Lead-Zinc	Underground	Interior	Hydraulic Stowing	Thickened Slurry
Limestone	Underground	Interior	Truck Dumping	Moist Filter Cake

The impacts of sludge disposal were assessed based upon a range of average mine conditions and range of untreated sludge characteristics common to each region. Methods for mitigating impacts were then assessed, taking into consideration factors such as sludge treatment, modification of disposal operations, control of site selection, and leachate collection and treatment.

a. Physical Impacts of Untreated Sludge

In the disposal of untreated sludge in mines the physical impacts of principal concern are: uncontrolled flow or seepage of sludge during disposal operations, consolidation of sludge deep-layered in surface mine pits, and the potential for liquefaction of sludge after disposal has been completed.

In order not to overly disrupt mining operations it is important in surface mine disposal that the sludge be relatively dry so that it can be easily handled and have minimal tendency to flow. In underground mines, liquefaction would be of principal importance where bulkheads are not employed to retain the sludge. Bulkheads would be part of a system employing hydraulic stowing but would not normally be included where pneumatic or dry stowing is employed.

Consolidation of sludge is of prime importance in surface mines where deep layers of sludges (greater than 5-10 feet) are created, particularly where the overburden is relatively shallow. The significance of consolidation depends on the time required for most of the settlement to occur and the ultimate proposed use of reclaimed strip mine land.

Both consolidation and liquefaction potential will importantly depend upon the properties of the sludge as well as the manner of sludge placement and loading on the sludge. As of the writing of this report there is no definitive data available on the properties of sludge relative to these effects.

b. Effects of Untreated Sludge on Water Quality

Most mines are wet, and it can be assumed that groundwater overlying the mined area will eventually flow into the mined area and saturate any FGD sludge deposit. Sludges disposed in surface mines may be subjected to groundwater flowing through unconsolidated sediment and broken rock overburden. Underground mines receive groundwater flowing through cracks, fissures, and faults in overlying (and underlying) strata into the mined area. Under most mining conditions, FGD sludge is expected to be saturated unless measures are taken to isolate the sludge either by diverting groundwater or placing the sludge above the water table. Leachate from the sludge can move into groundwater. Significance of the impact of the leachate on groundwater will, of course, depend importantly on the total quantity of the constituents leached as well as its concentration. To some degree, leachate concentrations will be affected by the composition of the infiltrating water.

Chlorides and sulfates are the major soluble species in FGD sludge, and in most cases, total dissolved solids (TDS) in the leachate plume would be expected to exceed recommended drinking water standards. Other species such as cadmium, mercury, and zinc would also be expected to be substantially raised in waters receiving sludge leachate; however, TDS levels should "red flag" contamination.

Little attenuation of soluble species is expected for most mine disposal situations. In most cases, the sludge would rest on rock strata in a layer below (and possibly partially mixed with) broken rock overburden, and there would generally be little or no direct contact of sludge or its leachate with soil. Therefore, adsorption of leachate constituents will not be significant in the immediate vicinity of the mine, and precipitation is the only feasible attenuation mechanism in most cases. Aluminum, beryllium, cadmium, copper, cobalt, iron, lead, manganese, mercury, molybdenum., nickel, and zinc may be partially precipitated under neutral to alkaline conditions. If limestone overburn is present, carbonate may form salts with cadmium, calcium, copper, iron, lead and zinc. Low levels of attenuation of arsenic, boron, selenium, and chromium are expected. No attenuation of sodium, chloride, or sulfate would be expected.

Leachate from the sludge layer is accessible to surface water by two pathways: (1) mine sump pump-out, which contains a mixture of groundwater, sludge leachate, and surface runoff and (2) groundwater recharge of down-gradient surface waters. The effect of waste leachate on surface water is obviously a function of the dilution factor of the receiving stream and its baseline water quality. In some cases, sludge leachate would be no worse (and conceivably better) than existing mine drainage, at least with regard to acidity levels and TDS. Therefore, leachate discharges may not have any appreciable impact on instream chemical concentrations in rivers polluted upstream by mining operations. However, leachate discharges to pristine small streams may show significant water quality impact. Cadmium, mercury, and zinc in particular may be increased to above fresh water aquatic life criteria. From a biological standpoint, TDS in general and these three heavy metals would provide cause for concern in small pristine receiving streams. In addition to the direct toxicity problems of the estimated increments in these metals, the potential problems of accumulation and synergism would also exist in larger streams. Mercury and cadmium are persistent cumulative toxicants and the toxicity of the latter can be increased by zinc.

c. Control Techniques to Minimize Adverse Impacts

Techniques available for minimizing adverse impacts of sludge disposal include:

- sludge processing or treatment
- selection of disposal method;
- collection and treatment of sludge leachate or runoffs; and
- selection of disposal site.

Sludge treatment by chemical fixation techniques may enhance physical properties and thereby ensure minimal operational and physical impacts, although well-filtered sludge (possibly admixed with ash) may, in many cases, be adequate to avoid most adverse operational and physical impacts. A treated sludge would also reduce mobilization of pollutants through reduction in the sludge permeability, decreased sludge contact area, and possibly reduction in the solubility of potential pollutants. However, some other constituents may be more immobile by such processes.

Adjusting the disposal operations to isolate the sludge from the groundwater would improve environmental impacts. If in surface mines, part of the rock overburden were deposited in the pit to a depth above the groundwater table prior to disposal of the sludge, then the rate of leachate generation would be lessened. However, such an operation may be technically impractical or economically unattractive. In underground mines, disposal between strata of low transmissivity (a function of permeability and hydraulic gradient) would limit the access of groundwater to the sludge deposit and thereby limit leachate production.

Collection and treatment of sludge leachate does not appear to be a viable alternative for controlling environmental impacts. Groundwater collection requires extensive pumping wells or infiltration galleries, and the chlorides and sulfates collected in the leachate cannot be readily treated by existing wastewater processes.

The best control techniques may be adequate evaluation and selection of the optimum site based upon the geologic conditions favorable to disposal and the characteristics of the sludge. Factors to be considered include: permeabilities of adjacent strata, hydraulic gradient of groundwaters through the mined area, seasonal location of the watertable, type of pyrite coal and resulting acid drainage formation, buffering capacity of background groundwater, distance and pathways to downgradient receiving surface waters, and potential for attenuation of dissolved species.

d. Potential Benefits from Sludge Disposal

Neutralization of Acid Mine Drainage

Coal mines, particularly eastern coal mines, have potential for the formation of acid mine drainage as pyrite is exposed to air and water. A surface mine which is reclaimed concurrent with mining hasless potential for acid drainage formation than one which is not immediately reclaimed. An underground room and pillar mine has the potential for continuously exposing pyrite to air and humidity, thereby allowing the worst acid mine drainage conditions to develop. An underground longwall mine, through controlled caving of the roof and pillar extraction, minimizes pyrite exposure and acid drainage formation. Disposal of FGD sludge could limit future acid drainage formation by sealing pyrite from air exposure.

Where there is presence of limestone in a surface or underground mine's overburden, neutralization of the acid mine drainage occurs. Similarly, FGD sludge has some ability to neutralize acid drainage. Calcium carbonate in the sludge would be expected to be the principal neutralization agent, since there is usually very little residual calcium oxide or calcium hydroxide. However, disposing of untreated sludge containing sulfite in very acidic waters may result in off-gassing of SO_2 which could prohibit such operations. In the western U. S. where the soil is often alkaline, such neutralization of acid mine drainage is not a factor.

Subsidence Control

Subsidence may occurring underground mines when the seam extraction panel is large enough to induce the mine roof to fail and collapse into the mine void. In room and pillar mining, pillars are left in place to provide roof support. However, after a room and pillar mine is abandoned, natural deterioration of the pillars may weaken them sufficiently to allow roof collapse. In longwall mining, controlled roof collapse is a part of the mining operation, and subsidence is expected to occur within several days of ore extraction.

Experience with hydraulic and pneumatic stowing of coal refuse and sandfill in conjunction with longwall mining has indicated lessening of subsidence from 90% of the seam thickness to 25-55%. FGD sludge is not expected to achieve the same degree of subsidence control, especially if it does not readily consolidate on placement.

In cases of long-term subsidence attributed to pillar deterioration, deposits of treated or untreated FGD sludge could partially seal the pillars from air exposure, groundwater seepage, and microorganisms. As a result, the reaction rates of chemical and biological pillar deterioration should be significantly lessened. However, the use of treated sludge in some manner either to line or replace pillars to allow additional coal extraction is not considered economically attractive.

Untreated Sludge as a Tailings Amendment

Tailings are highly variable in composition, as are FGD sludges. Tailings have been successfully revegetated for over fifteen years, usually using "soil amendments" such as limestone, sewage sludge, fly ash (where available), and, less often, soil itself. Materials used as soil amendments are chosen on a case-by-case basis to meet particular needs, but the potential for any material as a soil amendment depends upon its ability to alleviate any conditions that limit plant growth.

In general, FGD sludge may have some potential use for reducing acidity (unless it is acidic itself), reducing heat absorption and increasing moisture retention. It is doubtful if sludge could alleviate any problems with phytotoxins or salinity and may aggravate such problems in some cases. To prevent creating new problems, the sludge to be used must be screened for heavy metals, salinity, and acidity. But even an alkaline sludge with low salinity and heavy metals holds less promise as a soil amendment than either limestone or sewage sludge.

3.3 Refined Assessment - 1982

A more refined assessment(2) under the project was presented in 1980. A brief account of the results of this report are presented to provide some perspective.

Six key chemical and physical impact issues identified in that initial study were subjected to more detailed evaluation in this effort, using information and data obtained from the sources indicated by an "x" in the following table (a "-" means no information or data available):

	Information Sources		
Issues	ADL Testing	Independent Testing	Related Information
Physical			
Stability in Surface Mines	-	x	x
Freezing Effects	x	x	x
Fugitive Emissions	-	x	x
Chemical			
Dissolution of Total Oxidizable Sulfur	x	x	-
Offgassing $(SO_2/H/_2S)$	x/-	-/x	-
Concrete Corrosion	-	-	x

The testing performed and the related assessment focused on unstabilized waste because of the lack of definitive data on their behavior. When possible and appropriate, extrapolation to the potential fate and effects of stabilized wastes has been made.

Specific conclusions regarding the issues and impacts addressed in this refined assessment ar discussed below.

a. Stability - The requirements for physical stability of waste deposits in surface mine disposal operations depend upon the type of disposal operations, the mine characteristics, and the methods of mining employed. In general, it would be expected that most wastes at solid levels near optimum moisture content would have physical and engineering properties adequate to ensure acceptable stability (e.g., resistance to flow under its own weight due to disturbances from mining activities, etc.). In the case of sulfite-rich wastes, this would also certainly necessitate admixture of filtered (or centrifuged) waste with some amount of fly ash. Where the flue gas desulfurization) waste solids cannot be adequately dewatered and there is insufficient fly ash available for stabilization, admixture of both fly ash and lime may be required.

However, simply the addition of lime may not ensure short-term stability (prior to curing) if the waste is too wet. In such cases, stockpiling of the waste may be required to allow time for curing to begin (which also increases solids content) prior to disposal. Other control measures available, depending upon the type of disposal, to minimize stability problems include: production of gypsum rather than sulfite-rich material; mixing of waste with soil/overburden; control of placement to minimize rewetting (and saturation); and creation of containment walls of overburden either during disposal or after disposal (e.g., by placing the waste in discrete areas or on one side of the pit).

b. Freeze/Thaw Effects - Freezing of waste may alter the chemical as well as physical properties of wastes, which can affect handleability and ultimate strength developed. Laboratory testing of untreated waste samples indicated no significant effect of freeze/thaw on drainage of water from the waste. The degree of freezing and the effect of freezing on handleability can be minimized by dewatering (and admixture with ash) to achieve near-optimum moisture content. For areas of the country exhibiting extreme temperature conditions, use of heated trucks may be required (e.g., piping exhaust through truck walls) to ensure handleability.

Freezing would normally be expected to slow curing rates of stabilized wastes. If it occurs prior to the onset of curing, freezing may severely reduce the ultimate strength achieved. If it occurs after initiation of curing, there may be little or no affect on hardening. In order to increase curing rates and ultimate strength under winter conditions, it may be desirable to stockpile the waste for additional time (4-7 days) to allow onset of curing before disposal.

c. Fugitive Emissions - Although possible, emission of dust from FGC wastes in mine disposal operations is unlikely due to the relatively high moisture content of the wastes, fugitive dust emissions from stockpiles can be easily controlled. Drying of the waste pile surface will usually result in crustation; however, should dust emissions result, they can be minimized by wetting of the surface in much the same way dirt road surfaces are wetted.

d. TOS Dissolution - Dissolution of calcium sulfite from sulfite-rich FGD wastes can result in total oxidizable sulfur (TOS) levels in leachates ranging from tens to hundreds of ppm depending upon groundwater ionic strength, acidity and hardness. This can result in levels of chemical oxygen demand (COD) sufficient to deplete dissolved oxygen in groundwater and affect local receiving waters. Where sulfite-rich waste deposits might adversely impact aerobic ground and surface waters, the solubility of TOS should be a consideration in the impact of waste leachate. In many cases, the concentration of TOS, which represents an immediate oxygen demand, may not result in significant reductions in dissolved oxygen due to low leachate rates.

e. Offgassing Potential - There is potential for offgassing CO_2, SO_2, H_2S and possibly other gases from waste deposits in mines, particularly in underground mines. The release of SO_2 and H_2S is of greatest concern.

SO_2 offgassing can result from contact of neutral or slightly basic, sulfite-rich wastes with highly acidic mine waters (pH $<\sim 3.0$), especially during initial disposal operations where the quantity of waste is relatively small compared to the amount of acid. Longer term evolution of SO_2 is less likely to occur, but also, more difficult to predict as a generalization. The potential for short-term evolution can be minimized by: (1) avoiding placement of sulfite-rich wastes in mine areas containing highly acidic drainage; (2) pumping out and treatment of water prior to placement; (3) preneutralizing water with limestone; or (4) increasing the alkalinity of the waste by admixture of lime or limestone. Minimizing infiltration and/or acidification of groundwater in the mine by: (1) maximum filling of voids; (2) use of bulkheads; or (3) reduction of waste permeability by use of stabilization will also help reduce long-term SO_2 offgassing potential. If the waste is stabilized by admixture of fly ash and lime prior to disposal, additional lime may be required to also negate the effects of the acid water on the curing of the waste.

Release of H_2S from FGD wastes has been noted in a number of instances. Laboratory testing has also indicated the potential for H_2S release. It can occur from either sulfate or sulfite-rich materials due to the activity of sulfate-reducing bacteria. Some of the same measures used to control SO_2 offgassing may also be appropriate for H_2S offgassing. These include: proper selection of disposal sites and disposal methods; waste stabilization prior to disposal; and, in the case of underground disposal, maximum filling of voids and use of bulkheads to reduce contact with water.

f. Bulkhead Corrosion - Use of bulkheads as containment walls may be required in some areas of underground mine disposal operations. If constructed of concrete they may be susceptible to chemical attack by FGC waste liquors. Deterioration would be expected to be most severe for acidic wastes, especially those containing high levels of dissolved solids (e.g., sodium, magnesium, chloride and sulfate). There was very little information on cement and concrete behavior in the presence of liquors similar to those that might result from closed-loop operation of FGC systems. Parametric corrosion testing needs to be performed to assess the effects of FGC wastes and to develop a data base sufficient for specifying adequate cement/concrete mixes. Such testing needs to cover realistic and extreme ranges of scrubber liquors and leachate composition. Of particular importance would be concentration of chloride, sulfate, fluoride, sulfite, sodium and magnesium, and pH.

Measures which can minimize the potential for deterioration of concrete bulkheads include: coating of imbedded steel in reinforced structure; reduction in leachate generation by maximum filling of voids and/or waste stabilization and increasing the alkalinity of the waste to avoid developing acidic conditions.

4.0 DESCRIPTION OF TEST SITE

The field studies were carried out at the Center mine operated by Baukol-Noonan, Inc. using FGC wastes from the nearby Milton R. Young Station of the Minnkota Power Cooperative, Inc. These facilities are located near the town of Center, North Dakota which is approximately 40 miles northwest of Bismark. Appendix A provides some basic data on the power plant and the FGD system employed.

4.1 Generating Units and Coal Characteristics

There are two boiler/generator units at the Milton R. Young Station, and both are fired exclusively with lignite coal from the Center Mine. Pertinent specifications for these units are given in Table 4-1. While only the larger unit No. 2 is connected to the FGD scrubber system, flyash from both boiler units was fed to the scrubber.

While fly ash alkalinity was not measured on a regular basis, coal composition data was obtained frequently as part of the station power generation operations. Table 4-2 shows the range of properties found for coal burned from March 1978 through June 1979, the time period when the initial FGC wastes for this study were produced and emplaced. These data suggest that while the overall composition of the coal appears to be relatively constant, the variation in the contents of sulfur and sodium (which may be considered to be an indication of available alkalinity) might indicate that the FGD scrubber solids output would vary markedly over time. Unfortunately, no trace element data are available on the coal.

TABLE 4.1

Boiler/Generator Characteristics at Milton R. Young Station

	Unit No. 1	Unit No. 2
Boiler Type	cyclone-fired	cyclone-fired
Boiler output, maximum	265 MW gross 245 MW net	476 MW gross 438 MW net
Start up year	1970	1977
Coal comsumption (approx.)	4200 tons/day	8000 tons/day
Ash output (approx.)		
fly ash	110 tons/day	210 tons/day
bottom slag	225 tons/day	430 tons/day

Data source: (3)

TABLE 4.2

Typical Range of Coal Properties at M.R. Young Station*

	Btu/lb (as received basis)						
Date	**Average**	**Minimum**	**Maximum**	**Ash %**	**Sulfur %**	**Mositure%**	**Sodium %**
3/78	6681	6217	7069	8.51	0.53	35.8	1.25
	6513	6082	7121	7.85	0.63	37.3	3.12
	6460	5515	6950	9.48	0.81	36.7	2.40
6/78	6588	6124	6802	8.28	0.74	37.0	3.68
	6576	6103	6885	8.44	0.66	36.9	2.07
	6538	6168	6750	8.51	0.66	36.5	0.85
9/78	6565	6169	6853	9.38	0.75	34.4	1.01
	6527	6198	6866	8.76	0.73	37.2	2.46
	6495	6388	6775	10.24	0.62	35.6	1.56
12/78	6782	6081	7267	7.14	0.52	36.9	1.13
	6652	6184	7749	7.45	0.58	37.6	3.93
	6627	6246	6886	8.37	0.66	36.8	3.41
3/79	6531	5979	7503	8.30	0.53	36.8	2.32
	6630	6229	7408	8.43	0.82	37.0	1.19
	6792	5822	7386	9.64	0.82	34.0	1.65
	6726	6246	7628	8.98	0.71	35.2	2.02
7/79	6950	6498	7335	9.41	0.68	34.2	2.59
17 Month Range	6460- 6950	5515- 6498	6750- 7749	7.14- 10.24	0.52- 0.82	34- 37	0.9- 3.7
17 Month Mean	6625	-	-	8.66	0.67	36.2	2.16

*Data for "crusher" samples

Source: (4)

4.2 FGD Scrubber System

The flue gas desulfurization (FGD) scrubbing system installed on Unit No. 2 uses the alkaline fly ash from combustion of center lignite as the principal source of alkali for removing sulfur oxides. A slurry of fly ash in water is circulated through two parallel, independent spray towers.

The fly ash from both boiler units is collected by electrostatic precipitators, conveyed dry to storage and then slurried with recycled process water (i.e. thickener overflow and filtrate from solids dewatering) prior to addition to one of the two spray tower recycle tanks. When fly ash alkalinity is insufficient or not available (e.g. during unit startup), a slurry of lime slaked in fresh water can be added to the scrubber recycle tank. The alkali slurries are added to the recycle tank as needed to keep the pH within the operating range. Design pH range is 4 to 6.5, but the usual operating range is 5 to 5.5.

Each spray tower also has a wash tray of clear water (no deliberate addition of slurry) at the top with a pH controlled at 3.5 ±. The "wash loop" recycle system provides clear liquor for washing trays, while solids collected in this loop are diverted via a clarifier to the vacuum filters for dewatering and disposal.

A bleed stream from each of the spray tower recycle tanks is directed into a common thickener. Part of the overflow is returned to the spray recycle tank to control the solids content of the recycle slurry, and part is used to slurry incoming fly ash. The underflow from the thickener is sent to one of two vacuum filters for dewatering, and ultimate transport to the disposal site.

4.3 Mine Operation

The Center Mine operated by Baukol-Noonan, Inc. is located approximately three miles south of the town of Center, North Dakota. The region is semi-arid range and cropland having a topography featuring gently rolling hills with occasional small buttes and rock outcropings.

Two beds of lignite coal are accessible for surface mining at the Center Mine. The upper Kinneman Creek Bed lies within a few feet of the surface and is frequently too weathered to be of use in the power station boilers. The lower Hagel Bed has between 20 and 80 feet of overburden in the mined area, and averages between 8 and 22 feet in thickness.

The land is leased for mining, and is returned to the owners, generally to farming, after reclamation. The mining operation is carried out in a manner to facilitate reclamation. Top soil is removed and stored for return. Overburden is removed from a pit by the dragline and piled in the parallel mined-out pit which had been opened and mined on the previous pass. After removal of the final layer of overburden using a dozer, the coal is ripped, blasted and loaded onto large (180 ton and 120 ton) coal hauler trucks for transport to the power plant. As noted, overburden is returned during the next pass of the dragline. The resultant parallel lines of dumped overburden are bulldozed and contoured, and finally the top soil is returned. The width of all pits is maintained at 120 feet.

In the time period of this FGD waste disposal study (i.e., 1979 to 1981), there were four actively mined pits:

- In section 25, a 3000 ft pit trending N 60°E,
- In section 35, a 2000 ft pit trending S 45°E,
- In section 36, a 4500 ft pit trending N 60°E, and
- Between section 25 and section 36, a 2500 ft pit trending S 30°E.

These are shown in Figures 4-1 and 4-2. Mining operations are carried on throughout the year. In winter, additional ripping and blasting are necessary to overcome the deep frost penetration.

The mine, which was opened in 1970, is designed to produce 4.8 million tons of lignite per year for the "mine-month" M.R. Young Station. The draglines removed overburden 21 shifts per week. Coal loading and hauling was scheduled 10 shifts per week.

In 1976, to provide coal for the new 400 Mw Unit #2, Baukol-Noonan added a $12-million Page 757 dragline with a 68 cu yd bucket, four 180-ton Unit Rig coal haulers, a P&H 1900 shovel with an 18 cu yd coal bucket, a Caterpillar D-10 bulldozer and a Marathon Letourneau 1800 wheel-loader with a 22 cu yd bucket for in-pit blending of lignite to the desired heat content. Other mine equipment includes a 23 cu yd Page 736 dragline, a 10 cu yd P&H 1500 shovel, a 14 cu yd Michigan 475 wheel-loader, four 120-ton Dart coal haulers, six Cat D9H dozers, and six Cat 637 scrapers.

4.4 FGC Waste Disposal Practices

Since the mine was opened in 1970, both bottom slag and fly ash have been returned from the M.R. Young Station and disposed of in mined-out areas. Both materials are hauled by dump truck. The fly ash is mixed with 10-15% water to minimize dusting and to facilitate ease handling for placement. Fly ash has been placed nearly exclusively in V-notch areas while bottom slag is placed in notches and unneeded pit access roads.

As the alkaline fly ash scrubber became operational, much of the fly ash was diverted to it, and fly ash disposal was necessary only during extended scrubber outages. The wet scrubber filter cake is transported in specially equipped rear dump trucks which have a gasket seal along the rear dump gate (to prevent any liquid loss during transport) and a dump bed which is heated by the engine exhaust gases (to prevent freezing of wet waste to the dump body in cold weather). In practice, some 3 to 4 tons of bottom slag is placed on the bottom of the dump body prior to loading the 24 to 28 tons of wet scrubber cake; the bottom slag "liner" facilitates removal of the scrubber waste during cold weather dumping.

For these tests, alkaline ash scrubbing wastes were placed in V-notch and pit bottom locations as discussed in Section 5. Lime scrubbing wastes as well as excess fly ash and bottom ash were dumped in a designated area in the Section 25 pit. In these tests as well as in previous disposal, wastes were not placed in pit areas having standing water (e.g. certain parts of Section 35).

5.0 PROJECT DESCRIPTION

5.1 Objectives and Approach to Project

5.1.1 Objectives

The overall objective of this program has been to evaluate the feasibility of disposal of FGC wastes in mines as an alternative to landfill or ponding disposal. The program has been carried out in three phases. The results obtained from the first two phases were described in Section 3.2 and 3.3.

Phase III described in this report involved field demonstration of one of the feasible mine disposal options at a western surface coal mine. The objectives of this effort were twofold:

- The environmental objectives of Phase III were achieving an understanding of the effects both of the character of the FGC waste and of the mode of disposal on groundwater quality, and if possible, differentiating the effects due to the presence of the waste from those due to the mining and reclamation operations only. In addition, comparison of the leaching behavior of the emplaced wastes with the results of laboratory leaching column studies afforded an opportunity for testing the validity of such predictive tests.

- In the engineering/cost area, the objectives were to develop detailed cost estimates for the actual disposal operations, and to compare these estimates to the actual costs incurred by the test site operators.

5.1.2 Approach

The principal areas of concern for the environmental assessment included the effects of FGC waste disposal on groundwater and non-point source surface waters, and the effects of mitigative design, management and costs of practices on those receiving media. The engineering/cost assessment focuses on the costs associated with the design, management and control options examined.

The approach taken involved carrying out a series of sequential data gathering and assessment steps designed to afford an appropriate data base and to provide general guidance in its assessment.

- Geological and geohydrological data on the site and environs are gathered during the site development activities which also included placement of water wells and piezometers.
- Data on the composition and characteristics of waters, wastes and geologic strata of interest are obtained during the sampling and analysis activities.
- Using the site data, data from the laboratory tests, as well as the existing background on FGC wastes and disposal effects, cause/effect relationships are developed, and tested, to fit the measured site data.
- The cause/effect hypotheses are used to develop projects of the generic implications of effects observed at the test site to other similar FGC waste disposal scenarios.

The approach taken to obtain the desired information and data on both environmental effects and economic costs involves establishing and maintaining close coordination with the power plant and mine personnel and establishing and operating an extensive network of groundwater sampling wells and waste and soil sampling points,all of which afford samples which can then be subjected to extensive chemical and/or physical analyses. These environmental monitoring and sampling activities have been carried out in selected areas of the disposal site where control of the type and placement of waste were such that any observed environmental effects could be attributed to that waste with reasonable certainty.

The economic factors and operational feasibility of the two disposal modes were evaluated for the entire mine disposal operation, including disposal of FGC waste and excess quantities of fly ash and bottom slag.

5.1.3 Project Organization and Responsibilities

The environmental and economic assessment programs were carried out principally through the coordinated efforts of two groups, one from Arthur D. Little, Inc., and the other from the University of North Dakota (UND). In addition, officials and staff from both the power company (Minnkota Power Cooperative, Inc.) and the mine (Baukol-Noonan, Inc.) provided valuable assistance and cooperation in emplacing selected waste materials at particular locations by providing ready access to the study areas and in providing details of both capital and operating costs relating to generation and disposal of these wastes.

The actual sampling and analyses as well as the day-to-day coordination of the test program has been carried out by the University of North Dakota under EPA Grant No. R805459. Their responsibilities included sampling and characterization of the physical and chemical properties of the waste and soil materials, establishing and maintaining the network of groundwater monitoring wells, analysis of samples from these wells to detect the effects of placement, geochemistry and weather on the mobility of waste-related substances. UND also carried out the leaching column studies. The UND team provided an initial interpretation of the results of all of the tests and prepared a report of their work.

Arthur D. Little, Inc., has provided an overall review of the test program and results, including assistance in the supervision and coordination of the field operations at the mine. Arthur D. Little, Inc., had principal responsibility for the collection and evaluation of the engineering and cost data. In addition, Arthur D. Little, Inc., prepared this final report on the project incorporating and assessing the results of the UND test program.

5.2 Environmental Data Acquisition

5.2.1 Overview

The environmental study tasks in this program were strongly dependent upon program data-gathering activities which are comprised of both field-related and laboratory-related tasks. While some data on the composition and leaching of alkaline-ash scrubbing wastes are available from studies carried on at the Grand Forks Energy Technology Center Department of Energy), virtually all of that data had been obtained on wastes produced in pilot-scale scrubbing reactors, rather than a full-scale unit. Since the alkaline ash scrubbing unit at the Milton R. Young Station is the first of its kind to utilize North Dakota lignite ash, no data correlating the properties of sludges from pilot and full-scale facilities has been available.

In addition to the fly ash FGD waste, the plant also yields quantities of bottom ash, lime-derived scrubber waste and, during some periods, excess fly ash. At the outset of this study, it was desired to measure the effects of disposal of fly ash-derived waste together with that amount of bottom ash which is used as the truck bed liner. Hence, it was necessary to isolate the test materials and area from the remainder of the waste disposal activities.

As shown on the maps in Figures 5-1 and 5-2, the pit and v-notch sites chosen for the environmental assessment tests were at a sufficient distance from the remainder of the disposal areas so that a high degree of certainty exists that groundwater flow will be from unmined regions through the emplaced wastes and thence to the monitoring wells. In this way, it was hoped that the leachate impacts from wastes other than fly ash derived would be minimized.

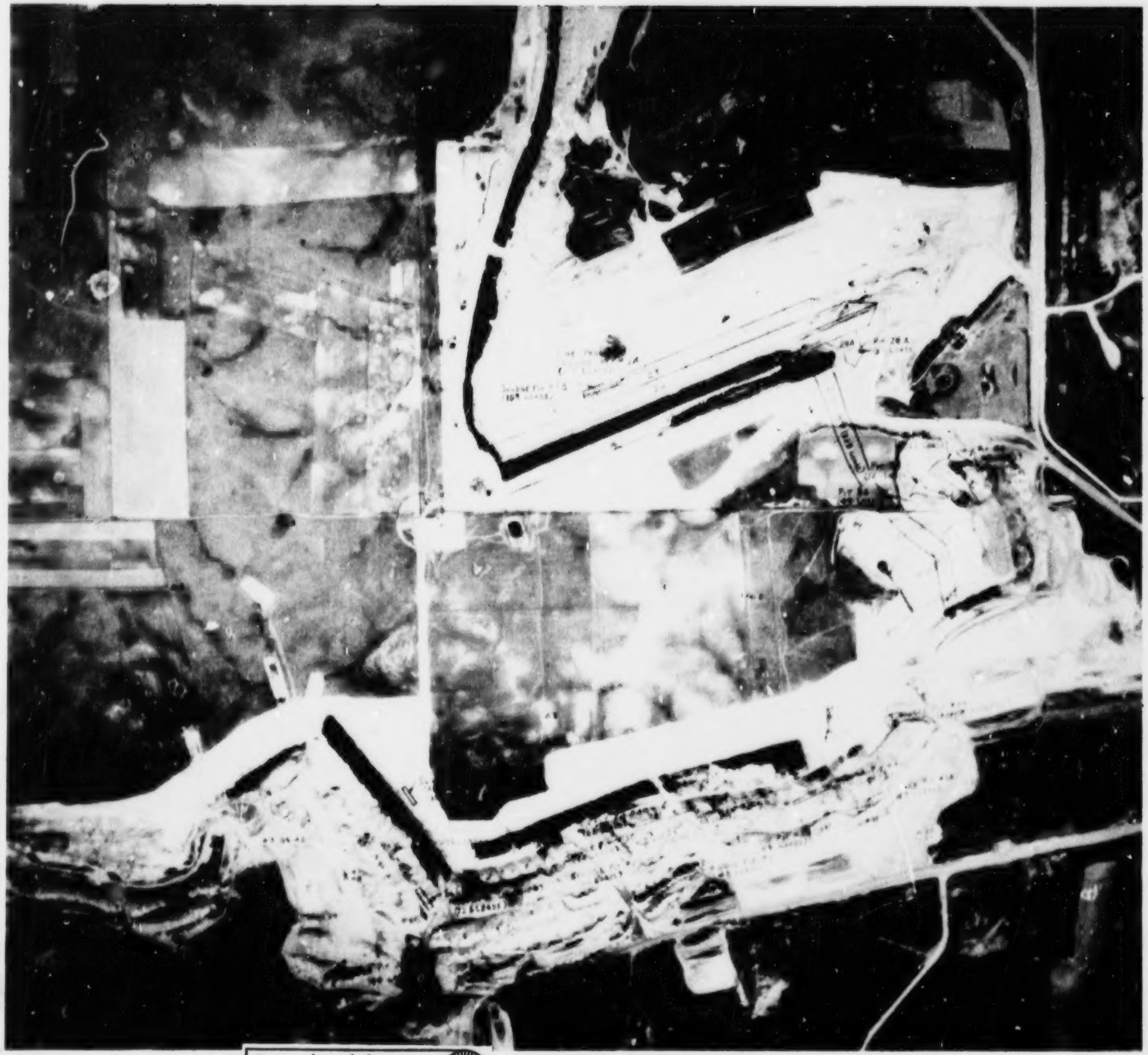

FIGURE 5-1

Aerial View of
Baukol-Noonan Mine,
Center, N.D. as of
June 27, 1978.

Reproduced from
best available copy.

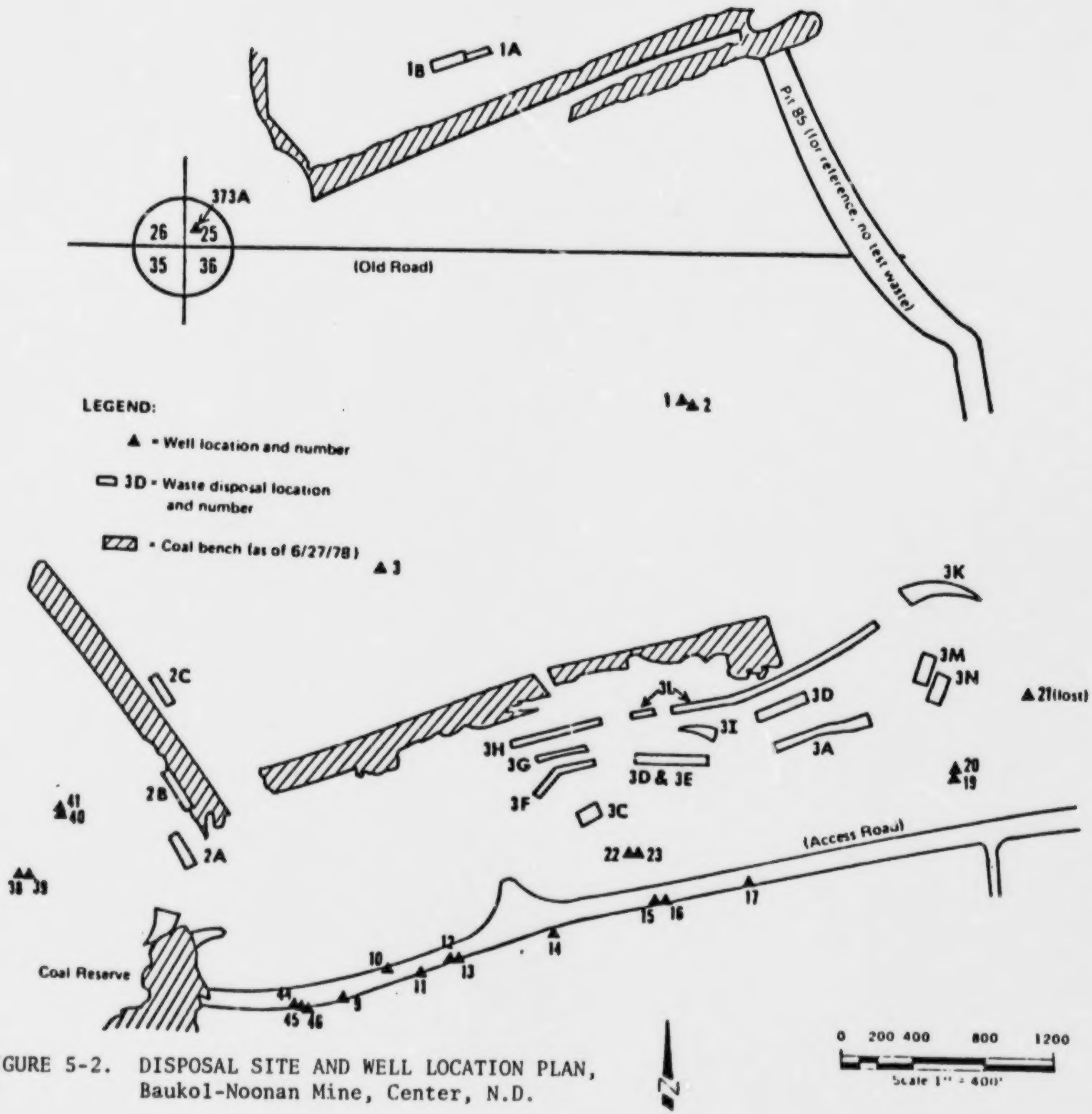
1B
1A
373A
26
25
35
36
(Old Road)
Pit 85 (for reference, no test waste)
1
2
LEGEND:
▲ = Well location and number
▭ 3D = Waste disposal location and number
▨ = Coal bench (as of 6/27/78)
3
3K
3M
3N
21(lost)
2C
3L
3D
3I
3H
3G
3D & 3E
3A
20
19
41
40
2B
3F
3C
2A
(Access Road)
22
23
38
39
17
15
16
12
14
Coal Reserve
10
13
11
44
9
45
46
N
0
200
400
800
1200
Scale 1" = 400'

FIGURE 5-2. DISPOSAL SITE AND WELL LOCATION PLAN, Baukol-Noonan Mine, Center, N.D.

5.2.2 Field Sampling and Monitoring Activities

Representative samples of the waste materials were taken during or just prior to emplacement in the test area. These samples were placed in sealed containers and shipped to laboratories at UND for subsequent analysis and characterization. In addition, samples of the soil strata in selected portions of both pit and v-notch disposal areas were taken prior to disposal of the waste materials in each area. In each test area, at preselected times after disposal of the waste and return of the overburden, additional samples of both the emplaced waste and the soil strata immediately beneath were obtained by drilling down (with an auger) to a point just below the waste and into the underlying soil. The resultant vertical cross-section sample was then sealed in the thin-wall tube and sent intact to the UND laboratory for subsequent separation, characterization and analysis. In some cases, the interstitial liquors in the wastes and soil samples were recovered by the pressure (consolidation) technique at the field site and shipped back to the laboratories for analysis. Appendices B and C provide summary of data on samples taken at the site.

Forty-six groundwater wells were installed within the lignite aquifer and adjoining soil strata in unmined and previously mined areas. Of these wells, over half have consistently yielded amounts of groundwater usable for analysis. The maps in Figures 5-2 and 5-3 indicate the positions of some of the wells installed; some are outside of the map detail area. Appendix B provides more details.

Six of these wells were emplaced within unmined areas up-gradient of the selected test disposal sites, while others were emplaced in both previously mined areas and in positions which are immediately adjacent to, and presumably down-gradient of, the disposal sites. An additional series were installed in or near the disposal FGD waste (Figure 5-3). This array of test wells was expected to yield samples sufficient in number and volume to allow differentiation of water quality changes which could be attributed solely to mining and disposal of other wastes which result from the leaching of fly ash FGD waste materials.

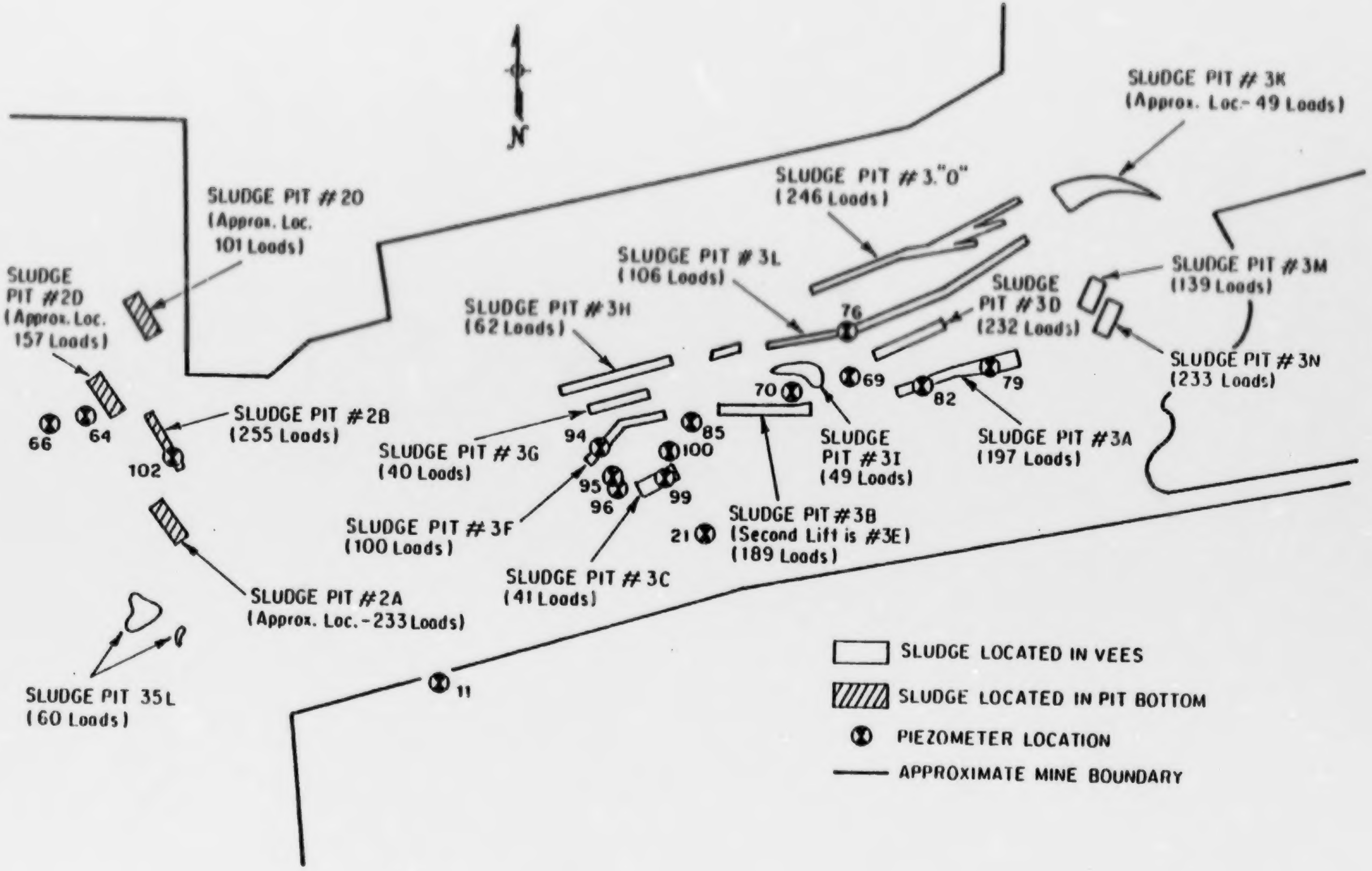
SLUDGE PIT # 3K
(Approx. Loc.- 49 Loads)
SLUDGE PIT # 3."O"
(246 Loads)
SLUDGE PIT #20
(Approx. Loc.
101 Loads)
SLUDGE PIT # 3L
(106 Loads)
SLUDGE PIT #3D
(232 Loads)
SLUDGE PIT # 3M
(139 Loads)
SLUDGE PIT # 3N
(233 Loads)
SLUDGE PIT #2D
(Approx. Loc.
157 Loads)
SLUDGE PIT #3H
(62 Loads)
76
69
70
82
79
SLUDGE PIT #2B
(255 Loads)
66
64
102
94
85
100
95
96
99
SLUDGE PIT # 3G
(40 Loads)
SLUDGE PIT #3I
(49 Loads)
SLUDGE PIT #3A
(197 Loads)
SLUDGE PIT # 3F
(100 Loads)
SLUDGE PIT #3B
(Second Lift is #3E)
(189 Loads)
21
SLUDGE PIT # 3C
(41 Loads)
SLUDGE PIT #2A
(Approx. Loc.-233 Loads)
SLUDGE PIT 35L
(60 Loads)
11
N
SLUDGE LOCATED IN VEES
SLUDGE LOCATED IN PIT BOTTOM
PIEZOMETER LOCATION
APPROXIMATE MINE BOUNDARY

FIGURE 5-3. LOCATION OF GROUNDWATER AND LEACHATE WELLS INSTALLED AFTER SLUDGE DISPOSAL IN VEES AND DRY PITS.

The water levels in each of the wells were measured monthly to aid in defining the local hydrogeology of the particular test area on a scale which would permit more accurate assessment of the true gradient and flow. Samples were taken at four-to-six-month intervals in order to provide baseline composition data.

Samples were recovered from groundwater wells principally by bailing technique. Where the volume permitted they were split into three portions: 500 milliliters were filtered through a 0.45 micrometer cellulose ester filter and then acidified with 2 milliliters of high purity concentrated nitric acid (metals analyses); a 1,500 milliliter sample was transferred to a precleaned polyethylene container without filtration or acidification (for analyses other than for metals); and a 100 milliliter sample was filtered and preserved with a few drops of dilute sulfuric acid (for nitrate analysis). The pH, sulfite content and conductance of the unfiltered and unacidified sample were determined in the field at the time that the sample was taken. All samples were then chilled in an ice/water mixture and transported at ice temperature to the UND Laboratory. Each sample was identified by a unique set of code numbers and letters which served to identify sample type, origin, and time of sampling.

Another field test carried out was measurement of vertical moisture profiles using a neutron absorption profiling technique. In this technique, a narrow hole is drilled through the soil strata and a close-fitting, thin-walled metal tube is inserted into the hole. A cylindrical probe containing both a neutron source and a detector is then lowered into the hole, and the instrument response, which is proportional to the moisture (hydrogen) content of the soil is measured as a function of depth. This technique is particularly useful both for locating moisture fronts which are traversing through the soil, and for estimating the actual moisture content of the soil.

Meteorlogical observations including amount and type of precipitation, temperature fluctuations, wind and humidity conditions were recorded daily at a site close to the disposal area.

5.2.3 Laboratory Testing and Analysis

Table 6.2 in Section 6 and Appendix C provide a matrix summary of the chemical and physical analyses and measurements which were carried on samples obtained from the disposal sites and the leaching column studies described below. During the initial period of this project, in order to provide a complete characterization of both liquid and solid samples, all major and trace constituents have been measured in all liquid phase and most solid phase samples. Once the background levels of most of these substances were established in the various sample types, then the necessity for complete analyses on each sample type was cut back. The analytical and physical measurements were carried out by the UND project team. The methods employed for chemical and physical analysis are given in Table 6.2. The details of the test methods were worked out and agreed upon by the UND and Arthur D. Little project team.

The liquid phases associated with both soil and waste samples were recovered by squeezing portions of the solids in a high-pressure press. In this technique, the solids are loaded into a 10-centimeter diameter x 13-centimeter high stainless steel cylindrical mold which is mounted on a grooved stainless steel base plate. A microprocess filter supported on several layers of fine-mesh stainless steel wire was placed in the base plate to provide rapid drainage of the expressed interstitial solution with minimal chemical contamination and physical carry over of fine particulates. A stainless steel piston was used to compress the solids within the mold using loadings of up to 22,000 kilograms for the waste materials and 14,000 kilograms for soils. Waste samples required approximately 2 hours, while the soil samples were consolidated for approximately 8 hours or longer. The collected interstitial liquors were then treated in the same manner as other solution samples.

Upon receipt, portions of the previously unfiltered and unacidified groundwater samples were filtered through 0.45 micrometer cellulose ester filters, and portions of the filtrate and of the unfiltered liquor were then used for the determinations of dissolved solids and total solids. The non-acid stabilized samples were then frozen until time for analysis. At that time, the entire sample was thawed and all analyses were carried out as expeditiously as possible.

5.2.4 Leaching Column Tests

In conjunction with this field test program, a laboratory study of the effects of actual and simulated groundwaters from the disposal test sites on FGD wastes and test site soils was being carried out using leaching column techniques. A large (55 gallon drum) sample of fly ash FGD waste was obtained from the Square Butte unit after operation had been stabilized. Portions of the sludge were packed into a series of columns and then eluted with a number of liquors produced either by elutriation of a particular soil or overburdened material obtained from the test site or with groundwater from a particular well in the disposal test site itself. Use of the elutriation technique (e.g., mixing a portion of the particular groundwater sample with successive portions of fresh, unextracted soil and then separating the solid and liquid phases) avoided the necessity and the attendant uncertainties of packing a layer of the soil above the layer FGD waste in the leaching column, and afforded more reproducible control of leaching rate. These leaching studies were carried out under both aerobic and anaerobic (nitrogen flushed) conditions. The resulting leachate solutions were subjected to the same chemical analyses as groundwater and interstitial liquors. The resulting elution profiles can be compared to the periodic measurements of groundwater leachates and soil interstitial waters found in the vicinity of the emplaced wastes.

5.3 Environmental Assessment Task

As indicated above, the key effort in the assessment is the development of cause/effect relationships from the site data base and the existing FGC waste disposal background information. Data and information generated during site development activities (geological survey, well placement, etc.), sampling and analysis, and laboratory tests are gathered and set in formats which facilitate inspection and comparison. It is particularly important that estimates of accuracy, confidence or validity, if available, be included within the data format to aid the comparison. Section 6.0 provides details on environmental assessment of this disposal practice.

5.4 Engineering/ Cost Assessment Task

The engineering/cost assessment task involved developing conceptual cost estimates (±30%) for both the original (which ceased operation in November 1981) and currently operating fly ash and FGD waste. handling/processing/disposal system at the Milton R. Young plant of Minnkota Power Cooperative, Inc. The objective in developing these cost estimates has been to provide one with sufficient cost data so as to make some comparison,not only between the original and currently operating solid waste disposal system at Milton R. Young, but also to compare the costs for these two modes of disposal with those for other type disposal modes.

To the extent possible, a modular approach has been employed in performing both the engineering and cost assessments. This approach entrails definition of the solid waste handling and disposal system under consideration and division of this system into a number of appropriate modules. At any particular plant site, up to six modules may be identified. These modules are are follows:

- Raw materials handling;
- FGC waste processing and handling;
- FGC waste storage;
- FGC waste transport;
- FGC waste placement; and
- Disposal site monitoring.

At the Milton R. Young plant, four such modules can be identified: FGC waste processing/handling; FGC waste storage; FGC waste transport; and FGC waste placement. The battery limits for both the former and currently operating disposal systems begin at the scrubber discharge and go to and include the actual placement of the waste in the mine. However, depending upon the nature of the engineering and cost data available individual modules had to be combined. This is generally the case when adequate data are not easily obtainable. In light of all this, the use of the module approach, to the extent practicable, provides for consistency in the assessments and also allows for easier cost comparisons to be made among these two cost estimates for actual operating systems and those costs reported in the literature for similar type systems.

In employing the module approach described above, it is necessary to determine the overall battery limits of the system and then subdivide the system into appropriate modules. Following this, one or more process flow diagrams depicting both the type and arrangement of the major pieces of equipment (including an equipment list and equipment specifications) comprising each of the modules is also prepared as part of the engineering assessment.

The cost assessment entails the development of both capital and operating cost estimates for the solid waste handling and disposal systems defined in the engineering assessment. Capital costs, including installation, were based on actual reported costs; however, in cases where such cost data were not available, independent cost estimates were developed. Depending upon the availability of actual cost data on the items of interest, capital costs were either reported as a total bottom-line capital cost or divided into three categories: direct, indirect, and other capital costs. Operating costs for the solid waste handling and disposal operations were similarly developed and divided into direct (raw materials, utilities, and operating expenses) and indirect (overhead expenses) costs to the extent practicable. Both capital and operating costs were reported in 1981 dollars.

6.0 SUMMARY OF PROJECT TASK ACTIVITIES

6.1 FGD Waste Generation/Disposal Operations

When this project was initiated in September, 1977, the projected operational schedules and plans of both the Minnkota Power Cooperative and Baukol-Noonan, Inc., appeared to be integrated well enough to assure that adequate quantities of fly ash-derived FGD waste would be available for disposal in pre-selected areas of the operating mine. Unfortunately, operational difficulties experienced with both the boiler and the FGD system resulted in a situation in which wastes of the desired quality (i.e., from fly ash operation rather than lime operation) were available for disposal only on an intermittent basis. In addition, unexpected difficulties with both equipment and mining operations resulted in alterations in the location and timing schedules indicated in the original mining plan put forward by Baukol-Noonan, Inc. As a result of the difficulties experienced by both parties, the placement of wastes in both pit bottom and v-notch test areas was delayed, and the actual disposal locations changed from those originally planned.

Disposal of the first fly ash FGD waste was delayed from the fall of 1977 until spring of 1978, and at that point placement of the last portions of the test waste occurred so late that the majority of the spring run-off had already taken place. In addition, the overburden return was delayed so that the waste itself was exposed to the run-off and rain rather than to a liquor permeating through the overburden.

The location and approximate dates of disposal and overburden return for the waste test areas are shown in Table 6-1. In all locations except the first v-notch (#1A), placement of the wastes occurred over a time period of weeks to months. The exact date of overburden return is likewise not known with certainty since this operation generally was accomplished between field visits of the Project observers, and was not specifically logged by the mining company. Substantial amounts of other FGC wastes, both ash and mixed scrubber waste, were disposed in other areas of Section 25 and 36, however, these were outside of the immediate study area.

TABLE 6-1

Areas of FGC Waste Emplacement Important to this Study[a]

Disposal Mode	Waste Type	Approximate Volume of Waste(cu m)[b]	Location Pit No. (Section)[c]	Approximate Dates	
				Disposal	Overburden Return
1st v-notch	lime FGD	500 cu meters	1A (25)	4/78	8/78
1st v-notch	fly ash FGD	2300	1B (25)	6/79-8/78	8/78
2nd v-notch	fly ash FGD	7500	3A,B,C (36)	9/78-10/78	7/79-5/79
2nd v-notch	fly ash FGD	3100	3G,H,I (36)	10/78-11/78	4/79-5/79
1st pit bottom	fly ash FGD	10,500	2A,B (35)	6/78-8/78	3/79-4/79
1st pit bottom	fly ash FGD	2200	2C (35)	9/78-10/78	3/79-4/79
v-notch	fly ash FGD	5100	3D (36)	9/78,12/78,2/79	4/79-5/79
v-notch	fly ash FGD	2000	3E(2nd lift on 3B)	12/78	4/79-5/79
v-notch	fly ash FGD	2200	3F (36)	11/78	4/79-5/79
v-notch	fly ash FGD	700	3K (36)	1/79,4/79,5/79	4/79-5/79
v-notch	fly ash FGD	3100	3M (36)	4/79	6/79-7/79
v-notch	fly ash FGD	3500	3N (36)	5/79	6/79-7/79
v-notch	fly ash FGD	2300	3L (36)	3/79,4/79	4/79-5/79

[a] Source: University of North Dakota, Mr. H. Gullicks

[b] Volume of wastes estimated from number of truckloads dumped at 22 cu meters per truckload

[c] Location codes are shown on map in Figure 5-2.

As indicated above, overburden return and reclamation was delayed in some areas somewhat beyond the time orginally intended for summer disposal. In that case, overburden return in the v-notch area was expected within a week or two, while overburden return in the pit bottom disposal area was expected during the next pass of the drag line, usually within one month. The delay in return of overburden did however, allow observation of the impacts which various environmental conditions, including drying and precipitation events, had on the physical characteristics of the waste.

After being dumped, the moist FGD waste remains soft for a few days while drying. Generally, the waste surface can support the weight of a person after a few days of exposure.

In some instances, excess liquor was observed to be draining from the base of the waste pile shortly after dumping. Nevertheless, no instances of apparent liquefaction of the waste, either from loads and/or vibration imposed by working equipment or from return of overburden onto the top of the waste were reported by the mining company operators. As noted in Table 6-1, multiple layers of waste were placed in some areas. In these areas, layers of mine spoil, approximately 0.3 to 0.6 meters (1 to 2 feet) thick were interposed by the mine operators, since they indicated that the waste alone was not strong enough to support rubber-tired disposal and earth-moving equipment.

In early 1979, a single truckload of FGD waste was dumped on the surface in an area where it would not be disturbed, and could thus be observed for some time. While the material remained in a condition in which it would readily crumble (slake) when immersed in water, tests at the UND lab showed a steady increase in unconfined compressive strength to over 8 kg/cm^2, indicative of some slow, likely pozzolovic reactions occurring. As expected, the surface of the waste was eroded by rains and wind, to some extent.

Observation of large areas of the emplaced wastes also showed that the coarse slag which is added as a layer onto the bed of the truck before loading the FGD waste ends up dumped in a localized area, as might be expected from the dumping process, and thus affords more highly permeable channels for water and liquor flow.

6.2 CHARACTERIZATION AND ENGINEERING MEASUREMENTS

6.2.1 Site Development

As stated earlier in Section 5.0, activities in this area include development and initial sampling of wells, acquisition of waste and soil samples and conducting field tests and observations.

Under this program, 46 groundwater observation wells were installed at various points on the test site. The wells were situated so as to yield samples of water from undisturbed (unmined) and previously mined (spoils) areas as well as from waste disposal areas. Wells intended to intercept FGD waste leachate were installed as close as possible to the projected or known disposal area in the presumed direction of groundwater flow. The maps in Figures 4-2 and 4-3 show the locations of the waste disposal sites and the array of groundwater wells in the immediate vicinity of those disposal sites.

In nearly all cases, boreholes were rotary drilled using air as the circulating fluid to minimize chances of water-related contamination. Observation wells of 5-cm (2-inch) diameter PVC pipe with 1.5 meter (5 foot) PVC screens were used.

Individual wells were screened at one or another depth with respect to the original lignite bed so as to permit collection of water from the same level ("base of the spoils") and from below the original water table. Geological and hydrogeological data on borehole stratigraphy and locations are given in Appendix B. The wells which are situated within the FGD disposal areas, as indicated on Figure 4-3, were installed after waste disposal and reclamation activities had been completed in those areas. Consequently they were available for sampling only at the very end of this test program. All boreholes in and near the wastes were drilled without use of water in order to avoid any contamination of or change in the composition of the water in the vicinity of the wells.

Acquisition of samples of emplaced wastes and associated soils from reclaimed areas was initiated by coring lime-derived wastes in a Section 25 pit bottom (1A and 1B) in November 1978, a few months after partial reclamation of the area. Cores of underlying soils in the area had been obtained prior to waste placement. Soil cores, prior to waste placement, were also obtained from a v-notch area near 3E (Section 36) and pit bottom 2B (Section 35). Coring of wastes placed in those areas was delayed until reclaiming of those areas, which was completed by August 1979.

In some cases, the emplaced FGD wastes remained uncovered for some period of time (weeks in some cases) prior to return of the overburden. This permitted direct observation of the physical properties and characteristics of emplaced wastes in an unconfined, unconsolidated state.

The locations of all well boreholes and coring locations were marked with flags and other markers. A careful survey of locations referenced to more-or-less permanent bench-marks was made in order to ensure subsequent location with respect to mining strips and waste disposal locations, which could be obtained from mining company records.

6.2.2 Chemical Sampling and Analysis

Water levels in the wells were checked at bimonthly to monthly intervals. Samples of the well water were taken approximately every four months. Samples were obtained using a PVC bailer; where recharge rates permitted, the wells were bailed at least twice before taking the retained analytical sample. Samples were filtered in the field immediately after acquisition, preserved with nitric acid and stored in cleaned plastic containers according to EPA protocols. No replicate samples or field blanks were taken.

During the time period from February 1978 to June 1979, 25 of the 46 wells yielded usable volumes of water during at least one of four sampling periods (Feb. 1978, July 1978, Nov. 1978, Feb. 1979). Some of the wells from other programs were also sampled during these periods to yield additional background data. Appendix B should be consulted for detailed listings of all samples obtained.

Very few samples of surface waters were obtained since little water was found within the pit areas of concern in this project, and most of that occurred only during the brief Spring wet season. Samples of FGD waste materials were obtained at quarterly intervals by physically sampling recently dumped wastes at the disposal site. Samples were selected at random. In addition, portions of some of the wastes which had been dumped during the intervals between sampling trips, were retained and supplied by a Minnkota Power Cooperative waste disposal supervisor. Solid samples were taken back to the UND laboratory prior to analysis or treatment.

A summary of the chemical analyses carried out on the water and solids samples is shown in Table 6-2. The details of the analytical methods employed are given in. These methods are, for the most part, coincident with EPA standard methods; measurements of sulfate and carbonate were made using improved, more reliable, methodologies. Exact procedural details for some methods (e.g., fusion conditions required to prepare some solids for trace metal analysis) were worked out as necessary using "spiked" samples and standard reference materials to ensure the accuracy of the method. For quality control purposes, reference water standards from EPA - Cincinnati or Environmental Resource Associates (South Chicago, Ill.) were analyzed on a monthly basis. In general, the results of these analyses fell with 5% of the reported values; UND did not issue a separate QC listing.

TABLE 6.2

Analytical Test Parameters for Waste, Water, and Ash Related Samples

Species Sought	Method	Sludge Solids	Sludge Liquors	Water	Ash
Major:					
Calcium	AA	X	X	X	X
Iron	AA	X	X	X	X
Magnesium	AA	X	X	X	X
Sodium	AA	X	X	X	X
Silicon	AA	X	X	X	X
Carbonate	CO_2 evolution	X	X	X	X
Hydroxide	Titration	X	X	X	X
Sulfate	Titration	X	X	X	X
Sulfite	Iodimetry	X	X	X	X
Minor:					
Arsenic	AA/Hydride	X	X	X	
Barium	AA	X	X	X	
Boron	Circumin Method	X	X	X	
Cadmium	AA	X	X	X	
Chromium	AA	X	X	X	
Cobalt	AA	X	X	X	
Lead	AA	X	X	X	
Manganese	AA	X	X	X	
Mercury	AA/vapor	X	X	X	
Potassium	AA	X	X	X	
Selenium	AA/Hydride	X	X	X	
Silver	AA	X	X	X	
Nitrate	Ion Specific Electrode		X	X	
Chloride	Ion Specific Electrode	X	X	X	
Fluoride	Ion Specific Electrode	X		X	
Miscellaneous Laboratory Tests:					
Sp. Gr	ASTM C188				X
Fineness(+325)	ASTM C204				X
Ignition Loss	ASTM C311				X
Total Alkalinity			X	X	
Total Solids			X	X	
Total Dissolved Solids			X	X	
Total phosphorous	APHA Test No. 425F		X	?	
COD			X	X	
Miscellaneous Field Tests:					
Conductance				X	
Dissolved Oxygen				X	
PH				X	
Temperature				X	
Sulfite	Iodimetry, Hach Kit			X	

It was also noted that samples which apparently contained significant concentrations of elements such as arsenic were reanalyzed using the method of standard additions.

Following acquisition of a set of samples, several weeks time were needed in order to complete all of the desired analyses because of the large number of measured analytes and parameters. In the interval between collection of the sample and completion of all tests, samples for chemical analysis were preserved by acidification or freezing.

6.2.3 Physical Sampling and Analysis

Samples of strata and soils closely under- and overlying the Hagel lignite bed were obtained in selected portions of the strip from which the coal had just been removed. Portions of overburden materials were also obtained. Samples were taken in thin wall ("Shelby") tubes by continuous coring techniques, since intact samples were desired for a number of the tests. Other grab samples of overburden spill materials were also obtained.

Samples of wastes were obtained from the dewatering filter and from piles of freshly dumped waste at the disposal site. A more detailed listing of the samples is given in Appendix C.
The physical tests and measurements carried out on these materials are listed in Table 6-3.

The test methods employed were standard ASTM tests, or equivalent well established methods. Details of the tests are given in Appendix D. The significance of the UND results is discussed in Section 7. While the standard tests protocols were followed, no replicate samples were measured elsewhere as a QC function.

TABLE 6-3

Physical Tests of Wastes and Soils

Parameter	Soils	Wastes
Moisture	X	X
Specific gravity	X	X
Liquid/plastic limits	X	X
Soil classification	X	X
Grain size distribution	X	X
Percent saturation	X	
Unconfined Compression	X	X
Permeability (field/max. density)	X	X
Standard Proctor compaction		X
Triaxial compression (field/max. density)	X	X
Freeze/thaw durability		X

Source: University of North Dakota (see Appendix D)

6.2.4 Leaching Column Tests

A series of leaching column tests were carried out as a means of exploring the possible effects that groundwater of various sources and compositions might have on disposed FGD wastes. In these tests, portions of a large single sample of FGD waste were packed into columns and eluted with various water solutions prepared by extracting or elutriating portions of the various soils and strata obtained during the site sampling visits. The resulting eluates were analyzed for metals and anions using the analysis methods applied to groundwater well samples from the site.

Measurements of the elutriation waters as well as the leaching eluates showed that contact of some of the overburden materials themsleves with water will yield significant concentrations of calcium, sulfate and total dissolved solids. After contact with the FGD waste, the resultant eluates show increases in sodium, potassium and magnesium in addition to the above ions.

Additional discussion of the significance of the leaching results is given in Section 7.

7.0 ENVIRONMENTAL ASSESSMENT

7.1 Overall Approach

The focus of this test program has been directed primarily at elucidating effects which the in-mine disposal of FGD and other utility-derived wastes may have on the quality of groundwater in the vicinity. This is an issue of special significance in the semi-arid, Western region settings where water supplies for both agricultural and some domestic purposes may be drawn from the aquifers (i.e., the lignite beds) which are likely sites for the disposal of the wastes. Other issues which are of lesser priority in this study include non-point source impacts on the quality of surface waters in the area, and the effects of waste physical properties on both disposal and mining operations as these may impact the local environment.

Because of this focus, data gathering and observation activities by the UND investigators concentrated on three areas of work:

- gathering field data and observations on geohydrology, climate and physical properties of wastes and soils at the site;
- collecting and analyzing samples of groundwater and wastes at a number of visits over an extended period; and
- conducting laboratory studies of chemical and physical properties of wastes and soils to provide data for making predictions about disposal effects.

The approach taken to the assessment of the results of the field and laboratory investigations involves a sequence of steps to qualify and to evaluate the data.

1. The data are assembled in formats which allow ready access and intercomparison, and are assigned an indication of their expected accuracy and/or reliability based upon the results of QC/QA activities and a knowledge of the test methodologies involved.

2. Chemical analysis results for waste liquors and extracts are compared with analogous solutions from virgin soils and mine spoils areas to identify possible "tracers" for waste leachate.

3. Site geology and hydrogeological data are reviewed in sufficient detail to afford some understanding of water balances and flow net at the site. From this base, some estimates of both direction and extent/distance of possible migration of waste leachate can be made. When combined with physical properties of the wastes, such estimates provide some indication of the probability of interception of waste leachate by any of the monitoring wells in the array, assuming no chemical interaction or retardation of leachate species.

4. The groundwater chemical sampling and analysis results are then examined in light of (2) and (3) above in order to define the nature of such cause/effect relationships as may be apparent from confirmation or lack of same for predicted chemical results. Other predictive tests including column elution tests are considered at this point.

5. Following elucidation of cause/effect relationships, the relative effects of different wastes and different disposal modes are considered, and predictions are developed for the range of wastes and disposal practices at the site. These predictions can then be extended to other areas and waste types to provide a generic assessment of this disposal approach.

It is recognized at the outset that the test data generated under the subject test program represent only the initial results from monitoring the groundwater well array, and that additional sets of data will be useful in providing further confirmation or refutation of such cause/effect relationships as may be suggested by these initial data. This current data base has been judged to be adequate for initial evaluation by the UND investigation team, and thus is deserving of evaluation.

7.2 Data Compilation

The chemical analysis data for groundwater and wastes is presented in a series of summary table formats in Appendices B and C. The individual tables are not reproduced here, but will be introduced in subsequent sections of this report. No QC/QA data are presented nor is there any direct reference given to any frequent QC checks other than to the analysis of standard water samples from the U. S. Environmental Protection Agency (Cinn., O) or Environmental Resources Associates (South Chicago, Ill.) on a monthly basis. However, while Arthur D. Little, Inc. was monitoring the active test program being conducted by UND, it was noted that there were certain data checks carried out at the UND labs including ion balances to check the major constituents and some standard addition "spikes" to check trace metals (9). In addition, for those samples in which significant concentrations of trace elements such as arsenic were found, the analyses were checked using the methods of standard additions (9).

In view of the absence of statistically defined measures of accuracy, only very general impressions of the accuracy of the data can be considered. In this context, it is better to consider the context of each of the catagories of samples (groundwater, wastes, etc.) and concentrations in attempting to arrive at a decision as to whether two sets of data are indeed different.

Physical test data are presented in Appendix D together with a listing of the methodologies employed. Again no QA function is noted.

7.3 Predictive Tests

Identification of Possible FGD Leachate Tracers

The fact that the FGD waste contains substantial concentrations of water-soluble substances which may be leached from the waste, and thus made available to the environment, is well documented, and further supported by the data in Table 7-1 which shows the range of porewater compositions found for a sample obtained from the M. R. Young Unit No. 2. These data were obtained as part of the UND investigation on porewaters recovered by means of a consolidation ("pressing") technique.

As an initial basis for comparison of whether the FGD liquors were likely to perturb the quality of the groundwater at the disposal site, some estimate of the range of site water quality was needed. At the time, only a limited number of actual ground water samples were available. However, simulated ground waters prepared by elutriation of various soils taken from the site with water from the Hagel lignite bed were available. These simulated ground waters were being prepared for laboratory (column elution) tests of the effects of various groundwaters on FGD wastes, and were expected to afford a reasonable estimate of the range of water quality which might be expected. A comparison of the compositions of these simulated ground waters, together with some initial samples from two monitoring wells, with the mean values for the FGD waste porewater results are given in Table 7-2. As an additional point of comparison, the composition found for a sample of the liquor associated with the bottom slag (which is co-disposed with the FGD wastes) is also shown. Comparison of these data, and the ranges given in Table 7-1 indicated that the FGD waste liquors were significantly more concentrated in major species, (including sulfate, sodium, magnesium and calcium) and in some minor species (including lead and cadmium) of the limited suite which were measured.

These data thus suggested that there were a substantial number of water soluble substances which could conceivably enter the ground water as the result of contact with disposed FGD wastes. The resultant

TABLE 7-1

Range of Porewater Composition Found in FGD Waste From M. R. Young Unit No. 2

Constituent	Porewater From 27 Samples of FGD Waste From Field Disposal Sites: Range	Mean	Std. Deviation	Leaching Column FGD Wastes Porewater
Arsenic, µg/L		Not Available		11.7
Cadmium, µg/L	1-156	18.6	38.7	547.0
Calcium, mg/L	298-530	423.2	53.0	395.0
Chromium, µg/L	11-63	32.1	14.8	26.9
Cobalt, µg/L	10-162	61.2	42.8	98.4
Lead, µg/L	17-219	88.0	55.8	58.0
Magnesium, mg/L	368-2903	1,633.2	802.1	2,310.
Mercury, µg/L		Not Available		0.7
Potassium, mg/L	7-354	44.3	105.5	332.0
Selenium, µg/L		Not Available		
Sodium, mg/L	237-3320	1,623	1,054.7	3,200.
Total Alkalinity (as $CaCo_3$)m mg/L	38-528	217.9	120.2	87.5
Chloride, mg/L	5-106	40.1	27.8	29.7
Fluoride, mg/L	1-28	13.7	7.1	5.0
Total Dissolved Solids mg/L	4032-39,968*	17,064*	7,145*	28,273.
Sulfate, mg/L	2473-19,038	10,763	4,029	17,106.
pH	7.5-8,9*	8.23*	0.37*	8.10

*Based on 24 FGD waste porewater sample analyses.

Source: University of North Dakota (see Appendix B)

TABLE 7-2

Examples of Water Compositions Which Might be Present in FGD Disposal Areas In Comparison with Mean Value for FGD Porewater

	Leaching Column Test Influent Liquors Hagel Lignite Bed Groundwater Elutriated With:								
	Oxid. Sand	Oxid. Glacial Till	Oxid. Brown Clay	Unox. Grey Clay	Unox. Silt	Hagel Lignite Bed Groundwater	Groundwater From the Base of the Spoil Piles	Water From the Effluent Weir of the Bottom Ash Settling Tank	Mean of FGD Porewater (Table 6-1)
Elutriations:	2	3	3	2	2	-	-	-	-
Constituent									
Cadmium, μg/L	<1	<1	<1	<1	<1	<1	<1	<1	19.
Calcium, mg/L	11.0	364.	212.	17.0	8.4	11.0	138.4	137.	423.
Lead, μg/L	7.1	8.4	3.1	9.4	12.8	2.3	6.1	6.5	88.
Magnesium, mg/L	33.2	260.9	163.4	16.4	13.4	6.8	150.1	66.2	1633.
Potassium, mg/L	7.4	11.2	20.8	22.8	18.0	4.8	20.8	26.4	44.
Sodium, mg/L	248.	420.	264.	296.	304.	384.	176.	360.	1623.
Total Alkalinity, as ppm $CaCO_3$	227.4	175.5	222.3	376.6	399.8	747.6	277.8	64.3	218.
Chloride, mg/L	8.9	21.1	9.9	7.6	8.9	3.8	5.9	9.3	40.
Fluoride, mg/L	0.7	0.8	0.8	1.0	0.8	1.3	<.1	0.8	14.
Total Dissolved Solids, mg/L	1016.	4135.	2599.	1078.	1121.	1,147.	1,947.	2,011.	17,064.
Sulfate, mg/L	408.	2417.	1070.	331.	401.	122.	1,056.	1,090.	10,763.
pH	8.7	8.5	8.6	8.8	8.7	8.4	8.1	8.2	8.2

Source: University of North Dakota (see Appendix B) potential for ground water quality degradation by one or more of many species, as well as the availability of a number of possible "tracer" species for signalling the possible presence of FGD waste leachate, suggested that the groundwater monitoring program should measure as many of the major and trace species as possible rather than concentrating on a few.

Leaching Column Tests

Because of the relatively high concentrations of soluble salts found in the interstitial water in samples of the FGD waste under consideration (see Table 7-1), the UND investigators sought to gain a better understanding of how those wastes might be effected by contact with localized groundwater. Data on the rate and nature of the displacement and/or extractions of waste-related species was of particular interest.

A series of leaching column experiments were carried out in which portions of the FGD waste were eluted by real or simulated groundwaters of differing composition, but all potentially present at the site. These experiments were in simulation of placement of wastes in a recharging zone (pit bottom) at the base of returned spoils, and were carried out under aerobic conditions. Analogous anaerobic tests were intended to be run at a later date.

The results of these tests indicated that soluble species both major and trace level ones, are displaced rapidly from the waste by all water composition tested, mostly within the first few pore volumes. Following displacement of the interstitial solubles, calcium and sulfate resulting from dissolution of the calcium sulfate forms in the waste, continue to be eluted over a long period of time.

Composition of FGD Wastes

The measurements of the solubles in FGD waste porewater, given in Table 7-1 indicated some substantial variations among the samples tested. In order to obtain additional insight into whether the variation might be due to scrubber process variability (or thus possible site or plant specific) or to compositional variation in the ash (hence more a function of coal/boiler variability), some additional analytical data were provided by the UND investigators, and are given in Table 7-3. While neither the sampling time frame nor sampling point are indicated, the data suggest that the overall FGD waste variability tends to mirror ash variations, and is less than the solubles variation in many cases. It should be noted--and was pointed out by the UND investigators in their report--that the soluble fly ash alkalis, i.e. the fractions of the Ca, Na, K and Mg which are present as reactive, accessible oxides rather than tied up in insoluble, glassy phases, may vary substantially as a function of coal composition and boiler operation. In addition scrubber process variability, including solution pH and solids content will also effect the solubles concentration in the waste interstitial solution.

Elutriation Tests of Wastes

The UND laboratory, as part of a collaborative study of various waste testing procedures carried out under another test program performed a limited series of shaker-type elutriation tests on both FGD waste and fly ash from the M.R. Young Unit No. 2. Since these data also provide some indication of potentially extractable materials, they are given in Table 7-4. Since the elutriation procedures (which are not noted in the UND Report) will result in the dilution of soluble species, these FGD

TABLE 7-3

Chemical Composition of Fly Ash and Fly Ash FGD Waste from the Milton R. Young Plant, Center, North Dakota

		mg/g										µg/g				
		Ca*	Mg*	Na*	K*	CO_3	Cl	SO_4	F	SO_3	Si*	Fe*	Cd	Hg	Se	As
Fly Ash FGD Waste	$\bar{x}$	104.8	19.0	15.0	13.6	3.2	0.01	195.6	0.3	0.1	166.3	50329	0.47	0.34	10.5	130.2
	s	24.8	3.0	4.7	4.3	8.1	0.00	57.5	0.06	0.1	39.8	6501	0.19	0.14	3.9	56.0
	n	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
Fly Ash	$\bar{x}$	122.1	35.2	28.8	12.5	0.5	0.01	93.4	0.2	0.2	258.3	63380	1.13	0.29	17.2	79.6
	s	14.7	2.0	10.9	0.3	0.1	0.00	12.7	0.4	0.04	10.6	2689	0.4	0.15	3.0	18.4
	n	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

*Calculated from % oxide

Note: numerical values given are the mean ($\bar{x}$), standard deviation (s) and the number (n) of samples analyzed

Source: University of North Dakota (see Appendix C)

TABLE 7-4

RESULTS OF A SHAKER-TYPE ELUTRIATION TEST OF FGD WASTE AND FLY ASH FROM SQUARE BUTTE ELECTRIC COOPERATIVE UNIT No. 2

	Concentration in the Elutriate (Range of 3 Elutriation Methods Used)	
Parameter	FGD Waste	Fly Ash
ph	4.99-6.58	6.96-11.46
Calcium mg/L	401-600	394-951
Chromium µg/L	16	31-160
Arsenic µg/L	2	34.6-127.0
Barium mg/L	0.225-.716	0.757-1.069
Cadmium µg/L	0.5-2.7	1.3-17.6
Lead µg/L	1.5-12.1	2.7-22.4
Mercury µg/L	0.3	0.3-0.4
Selenium µg/L	2	17.6-368
Silver µg/L	2-24	7-15

Source: University of North Dakota

waste data are understandably at the low end of the range found for the porewater of those wastes (Table 7-1). Nevertheless, the data in Table 7-4 do provide additional information on the FGD waste extractables, and also afford a comparison with the source fly ash. This will be discussed in more detail in Section 7.5.

7.4 Geohydrologic Setting

Appendix B describes the areal and site geohydrological setting. The principal authors of this Appendix are intimately familiar with geology and hydrology of the Center area, and are actively involved in a number of on-going investigations of the geohydrologic impact of strip mining and similar operations throughout North Dakota. Piezometric data have been gathered from many of the approximately 150 piezometers installed in and around the waste disposal area as well as other mined and unmined areas at Center. That piezometric data and interpretations are discussed in Appendix B.

The UND investigators concluded that the basal portion of spoils is saturated over most of the study site. Potentiometric head values in most of the piezometers in the spoils showed a fairly consistent rise over the period of the study, suggesting that equilibrium conditions had yet to be established in the spoils. Potentiometric head data suggested that groundwater recharge was occurring through the spoils. This was verified by tritium and oxygen-18 data obtained from 22 piezometers in the spoils area. The oxygen-18 data indicate that the water in the base of the spoils had not been subjected to significant evaporation as would be expected if recharge were due to the lateral movement of water from the adjacent mine pit. The tritium data indicated that the water in the base of the spoils was enriched in tritium relative to groundwater in laterally adjacent and underlying undisturbed units, indicating vertical movement and recharge of this water through the spoils.

These findings suggest that the spoils recharge, occurring through vertical infiltration, might have contacted the disposed FGD wastes, most of which was buried in V-notch locations (see Table 5-1 and Figure 4-2). While not noted by the UND investigators, some consideration may need to be given to localized collection and/or diversion of the precipitation (i.e. run-off patterns) brought about by the extremes in topography which existed in the disposal area prior to reclamation.

7.5 Cause/Effect Relationships

The results of sampling and chemical analyses of water in the monitoring wells are given in Tables 7-5, 7-6 and 7-7. Table 7-5 provides a summary of the compositional variations for wells which are not located near any deposited wastes, either by intent or because of the sporadic waste placement record in the early part of this test program. Tables 7-6 and 7-7 show the results obtained for individual sampling events for a number of the monitoring wells which were deliberately installed in or near known waste deposits after placement and reclamation were complete. The locations of these wells in the mine area are shown in Figures 7-1 and 7-2.

Those wells which were installed within or very near to actual FGD waste deposits after reclamation are identified in Figure 7-3 which shows the stratigraphic location of their screens. Since these wells were deliberately located so as to maximize the likelihood of intercepting waste-derived water or leachate--note that in some wells the screens are actually in the waste--then these wells are logical locations to look for water compositions indicative of FGD waste leachate. The results of the first few sampling activities at these wells are shown in Table 7-6 and 7-7. The high concentrations of sulfate, sodium and magnesium, all of which were identified in Section 7-3 as being associated with FGD waste liquors, which are present in Wells 94 and 99 particularly, suggest strongly that those wells are in contact with FGD waste-derived liquors. The results for Wells 79 and 76, which also lie beneath V-notch disposed FGD waste, show

Table 7-5. **Chemical analyses of groundwater from spoils and undisturbed units, Center Mine, Center, North Dakota**

	Field Temp °C	Field pH	Field Cond µmhos/cm	DO	TDS	Total Hardness	Ca	Mg	Na	K	HCO_3 mg/L	CO_3	SO_4	Cl	NO_3	F
	SPOILS															
$\bar{x}$	9.7	6.7	3880.0	0.8	3375.6	---	348.0	232.4	361.0	15.6	1165.4	---	1454.9	8.1	0.6	0.1
s	4.2	0.3	1243.2	0.4	910.7	---	97.5	90.1	255.1	8.9	413.1	---	536.7	4.6	0.4	0.1
n	21	21	21	15	16	---	16	16	16	16	18	---	18	18	13	15
high	16.5	7.7	8000	3.5	5338.0	---	519.0	431.2	1118.0	34.0	2113.0	---	2520.0	21.0	1.8	0.3
low	2.0	6.3	1830	0.2	1599.0	---	190.0	103.5	89.5	7.5	363.6	---	565.8	2.3	0.1	0.0
	KINNEMAN CREEK BED															
$\bar{x}$	10.4	6.7	1655.6	0.4	1229.3	404.3	84.3	51.9	249.7	18.8	651.1	1.1	372.2	8.1	1.8	0.1
s	2.8	4.6	437.1	0.2	333.3	227.0	47.0	20.3	122.7	11.3	208.7	0.4	137.5	8.0	2.6	0.0
n	9	9	9	5	9	4	9	9	9	9	9	3	9	9	8	6
high	16.0	7.5	2200	0.7	1631.0	731.0	165.0	94.4	441.0	48.6	1021.1	1.4	642.7	21.0	6.5	0.1
low	6.5	6.0	975	0.2	838.0	221.0	29.0	29.0	115.0	11.4	334.3	2.6	232.6	0.5	0.1	0.05
	HAGEL BED															
$\bar{x}$	9.5	7.1	2264.3	0.4	1774.0	94.6	105.3	74.3	297.4	10.7	681.4	8.0	668.3	7.0	1.3	0.1
s	2.9	0.5	1041.8	0.5	1056.3	---	116.7	72.3	202.3	5.5	218.5	9.0	604.8	6.3	2.4	0.2
n	20	20	20	13	19	1	17	17	17	17	18	2	19	19	14	14
high	14.5	8.0	3750	1.9	3874.0	---	337.0	202.0	810.0	23.2	1098.0	14.3	2087.0	28.0	8.5	0.7
low	3.0	6.4	900	0.1	649.0	---	8.0	2.1	72.4	4.2	412.2	1.6	41.2	0.5	0.0	0.0
	SAND 5m BELOW HAGEL BED															
$\bar{x}$	9.2	7.4	3453.8	0.6	2644.8	---	153.2	80.4	567.7	10.2	835.0	---	1217.0	6.3	0.6	0.4
s	2.0	0.9	932.4	0.5	985.0	---	136.1	74.8	247.6	2.2	327.7	---	663.3	3.3	1.0	0.5
n	13	13	13	13	10	---	13	13	13	13	13	---	13	13	13	13
high	12.0	9.3	4400	1.6	4428.0	---	431.8	260.0	880.2	14.0	1288.2	---	2539.0	11.0	2.9	1.4
low	5.5	6.4	1900	0.0	1413.0	---	30.9	12.7	5.9	.74	106.8	---	415.0	2.0	0.0	0.0
	SILT 15m BELOW HAGEL BED															
$\bar{x}$	8.7	7.6	2946.5	0.5	1983.2	78.6	53.6	35.7	636.5	10.5	1154.7	12.8	694.7	11.1	2.2	0.7
s	2.6	0.5	1345.0	0.5	911.0	40.2	52.0	41.9	252.1	6.8	413.6	0.3	658.0	15.6	8.7	0.7
n	47	47	47	35	44	4	47	47	47	47	47	2	47	47	41	38
high	14.0	8.4	8000	2.7	5056.0	128.0	191.5	186.0	1311.0	36.4	1942.2	13.0	1642.6	107.2	55.8	2.3
low	3.0	5.9	600	0.1	416.0	43.3	3.5	2.8	106.5	3.5	248.0	12.6	140.9	0.5	0.0	0.0

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Table 7-5. **(continued)**

	SO_3	B	Alk.	Fe	Mn	Cd	Hg	Se	As	Pb	Ba	Cr	Co
	mg/L			µg/L									
	SPOILS												
$\bar{x}$	3.8	1.0	954.7	555.6	1951.2	1.9	0.3	1.6	3.7	4.9	92.8	7.3	13.3
s	1.8	1.2	317.0	557.7	1100.4	2.4	0.3	1.2	2.9	7.2	93.5	4.9	11.9
n	14	11	15	16	16	16	15	12	12	10	10	10	16
high	8.0	4.5	1732.0	1470.0	4070.0	8.8	1.3	4.8	10.1	22.1	348.5	18.1	46.1
low	1.5	0.5	298.0	20.0	2.8	0.5	0.0	0.0	0.4	0.0	10.4	1.9	1.8
	KINNEMAN CREEK BED												
$\bar{x}$	5.0	---	507.0	484.0	325.8	12.0	0.1	2.5	1.0	7.1	51.6	2.5	6.6
s	4.2	---	237.8	369.4	200.3	16.7	0.1	1.3	---	5.4	12.0	1.6	1.1
n	2	---	4	9	6	6	2	2	1	5	2	2	2
high	8.0	---	837.0	1300.0	610.0	34.0	0.2	3.4	---	13.8	60.0	3.6	7.4
low	2.0	---	274.0	45.1	95.0	0.2	0.0	1.6	---	2.0	43.1	1.4	5.8
	HAGEL BED												
$\bar{x}$	4.9	0.9	655.2	220.2	1072.7	1.2	0.4	0.8	2.8	16.9	159.6	6.0	8.9
s	6.1	0.9	399.2	156.4	1120.9	1.1	0.2	1.1	2.1	25.5	257.3	6.7	9.5
n	9	6	16	16	15	15	14	7	6	8	8	8	14
high	20.5	2.8	2040.0	580.0	3440.0	4.4	0.7	2.9	6.5	76.5	792.0	20.0	33.5
low	0.5	0.5	338.5	50.0	50.0	0.5	0.2	0.0	1.0	0.4	42.7	0.3	0.0
	SAND 5m BELOW HAGEL BED												
$\bar{x}$	5.9	3.5	684.5	236.2	660.0	5.0	0.3	1.6	8.1	11.5	54.2	13.0	21.6
s	8.6	2.3	268.7	222.9	765.6	7.1	0.3	1.8	13.4	12.2	22.7	11.4	18.7
n	13	9	13	13	13	13	13	9	9	7	7	7	13
high	31.0	7.2	1055.9	630.0	2930.0	23.5	0.8	6.1	37.6	38.8	79.5	36.8	66.1
low	1.0	0.5	87.5	20.0	120.0	0.5	0.0	0.0	0.9	3.2	7.2	2.9	0.0
	SILT 15m BELOW HAGEL BED												
$\bar{x}$	8.4	5.1	956.9	227.3	265.1	2.6	0.6	2.2	3.6	14.1	154.4	12.9	20.8
s	11.6	10.3	337.4	150.4	144.2	5.2	1.0	1.8	3.4	10.8	197.9	10.5	15.6
n	36	18	39	47	45	45	41	28	27	29	25	25	41
high	55.0	39.3	1592.0	640.0	770.0	25.2	4.6	6.1	14.0	39.0	758.0	52.6	83.9
low	1.0	0.5	203.0	30.0	49.0	0.2	0.0	0.0	0.0	0.9	31.6	2.1	0.2

Table 7-6. Groundwater analyses from piezometers in area of FGD waste and fly ash disposal, Center Mine.

Piezometer No.	Date	Field Temp.	Field pH	Field Cond.	TDS	Alk.	Ca	Mg	Na	K	HCO3	SO4	Cl	NO3	F
					mg/L										
Piezometers Showing Influence of Fly Ash FGD Waste															
C 94	03-27-80	8.0	6.30	>8,000	7,872	163.4	195.3	615	900	55.0	199.4	4,917	10.7	-	<0.1
C 94	06-09-80	11.0	7.30	13,600	7,772	191	307	262	493	32	233.0	3,572	-	-	-
C 102	06-09-80	14.0	7.20	12,400	7,198	633	186	105	1,845	24	772.3	4,343	-	-	-
C 99	03-29-80	9.5	6.15	8,000	7,220	553.4	215.5	530	960	24.2	675.2	4,111	22.0	-	0.73
C 99	06-09-80	14.0	7.25	10,000	6,564	645	393	408	1,050	24	786.9	3,811	-	-	-
Piezometers Showing Influence of Fly Ash															
C 10	11-10-78	6.0	12.10	>8,000	5,425	485	32.8	0.2	1,550	198.4	591.7	3,213	27.0	0.60	1.4
C 10	07-06-78	11.5	11.74	>8,000	5,548	715.2	28.2	0.1	1,340	9.7	872.5	3,015.5	19.8	1.13	1.7
C 10	02-24-79	4.5	11.85	>8,000	5,715	500	30.8	1.3	1,517	198.3	610.0	3,607.3	26.5	0.13	1.65
C 133	06-19-80	15.0	8.75	21,600	12,270	182.7	780.7	39.9	3,364	500	209.3	8,893	11.9	0.15	0.16
C 136	05-20-80	13.0	7.80	29,000	12,420	364.1	240	123.0	5,119	280	432.3	9,265	13.0	0.10	0.49
C 136	07-28-80	13.2	7.9	6,500	10,690	381.6	220.4	131.9	2,963	287.6	460.3	6,723.2	11.3	0.21	0.66
C 139	05-20-80	13.0	6.95	13,600	6,960	569	515	312.9	1,303	75	688.1	4,357	9.0	0.40	0.23
C 139	07-28-80	12	7.25	7,800	6,720	578.8	524.7	292.8	953	35.4	698.6	3,428	9.8	0.24	0.32
C 140	06-19-80	14.5	11.55	99,200	52,650	534.9	130.4	20.6	13,573	2930	24.5	36,820	74.9	0.34	0.84
C 140	07-28-80	17.0	11.62	>8,000	50,110	684.6	97.7	19.6	16,947	-	16.7	31,045	57.7	0.23	2.34

Position of Screened Interval

C 94	In spoils, offset from FGD waste approximately 10 m
C 99	In base of spoils, 11 m below FGD waste
C 102	In base of spoils, slight offset from FGD waste
C 10	In base of spoils, offset from fly ash unknown distance
C 133	In base of spoils, offset 20-25 m and 10 m below fly ash
C 136	In base of spoils, 11 m below fly ash
C 139	In base of spoils, 7.5 m below fly ash
C 140	In spoils, immediately below fly ash

Table 7-6. (continued)

Piezometer No.	Fe	Mn	Cd	Hg	Se	As	Pb	Mo	pH	SO_4mg/L
	←				μg/L			→		
Piezometers Showing Influence of Fly Ash FGD Waste										
C 94	130	4,410	1.8	<0.3	<2	3.0	-	-		
C 94	20	-	<1	<0.3	<2	<2	7.3	-		
C 102	90	-	3.3	<0.3	5.6	<2	29	-		
C 99	50	1,740	1.4	0.6	2	2	-	-		
C 99	250	-	<1	<0.3	<2	<2	7.4	-		
Piezometers Showing Influence of Fly Ash										
C 10	30	24	3.6	0.7	13.6	204.6	58.0	-	12.1	3,713
C 10	20	10	<1	0.8	3.8	171.8	33.1	-	11.7	3,016
C 10	110	20	4.7	0.3	8.2	97.8	-	-	11.9	3.607
C 133	140.7	-	3.75	-	-	13.3	7.67	17,019	8.8	8,893
C 136	4	-	0.82	-	-	22.6	236.0	4,500	7.8	9,265
C 136	308	495	0.25	-	0.56	35.3	28.1	5,466	7.9	6,723
C 139	2,080	-	0.39	-	-	0.3	60.0	640	7.0	4,357
C 139	2,590	6,500	0.9	-	0.56	6.2	16.1	218	7.3	3,428
C 140	21.8	-	0.78	-	800	550	34.1	23,700	11.6	36,820
C 140	1,376	271	4.3	-	760	613	-	38,460	11.6	31,045

TABLE 7-7

ADDITIONAL GROUNDWATER ANALYSES FROM PIEZOMETERS IN FGD WASTE

Designation - Sample		Center 94	Center 94	Center 94	Center 99	Center 99	Center 99	Center 102	Center 102	Center 102	Center 76	Center 76	Center 79	Center 79
Date Collected		3/27/80	6/9/80	9/9/80	3/27/80	6/9/80	9/9/80	3/27/80	6/9/80	9/9/80	6/9/80	9/9/80	6/9/80	9/9/80
Aluminum	μ/l		<50	26		<50	475		155	234	<50	78	<50	74
Arsenic	μg/l	3.0	<2	2.5	<2	<2	3.7	5.5	<2	5.6	2.9	2.1	<2	<2
Barium	μg/l		50			88			81		272		63	
Boron	mg/l	1.1			1.6			2.6						
Cadmium	μg/l	1.8	<1		1.4	<1		4.5	3.3		<1		<1	
Calcium	mg/l	195.3	307	404	215.5	393	331	65.8	186	560	65	58	215	416
Chromium	μg/l		<2	25		3.8	16		19	61	<2	32	<2	13
Cobalt	μg/l	22.2			12.7			31.9						
Iron	mg/l	0.13	<0.02	.04	<0.05	0.25	.40	0.25	0.09	1.3	0.03	.06	0.05	.04
Lead	μg/l		7.3	11		7.4	7.6		29	17	<2	4.2	16	7.6
Magnesium	mg/l	615	262	596	530	408	457	49.5	105	151	34	30	358	421
Manganese	mg/l	4.1			1.74			0.38						
Mercury	μg/l	<0.3	<0.3	.41	.06	<0.3	<.1	<0.3	<0.3	.41	<0.3	<.3	<0.1	<.3
Potassium	mg/l	55.0	32	49	24.2	24	20	11.8	24	27	12	9.9	6.2	14
Selenium	μg/l	<2	<2	2.6	<2	<2	2.8	<2	5.6	<2	<2	<2	<2	<2
Silicon	mg/l	2.0			8.2			11.4						
Silver	μg/l		<1	7.1		<1	1.2		1.7	13	<1	<1	<1	4.5
Sodium	mg/l	900	493	730	960	1050	776	823	1845	2200	322	377	331	567
Total Alkalinity as ppm	$CaCO_3$	163.4	191	221	553.4	645	687	553.8	633	628	794	798	659	626
Chloride	mg/l	10.7			22.0			8.5						
Dissolved Oxygen	mg/l													
Phosphate	mg/l	0.05			0.80			0.05						
Total Dissolved Solids	mg/l	7872	7772	7644	7220	6564	5917	3267	7198	8128	1102	1082	3497	5080
Sulfate	mg/l	4917	3572	4988	4111	3811	3500	1465	4343	5108	222	148	1922	2891
Chemical Oxygen Demand	mg/l	22			257			325						
pH		6.30	7.30	7.55	6.15	7.25	7.25	6.76	7.20	7.40	7.35	7.00	7.25	7.55

Source: (10)

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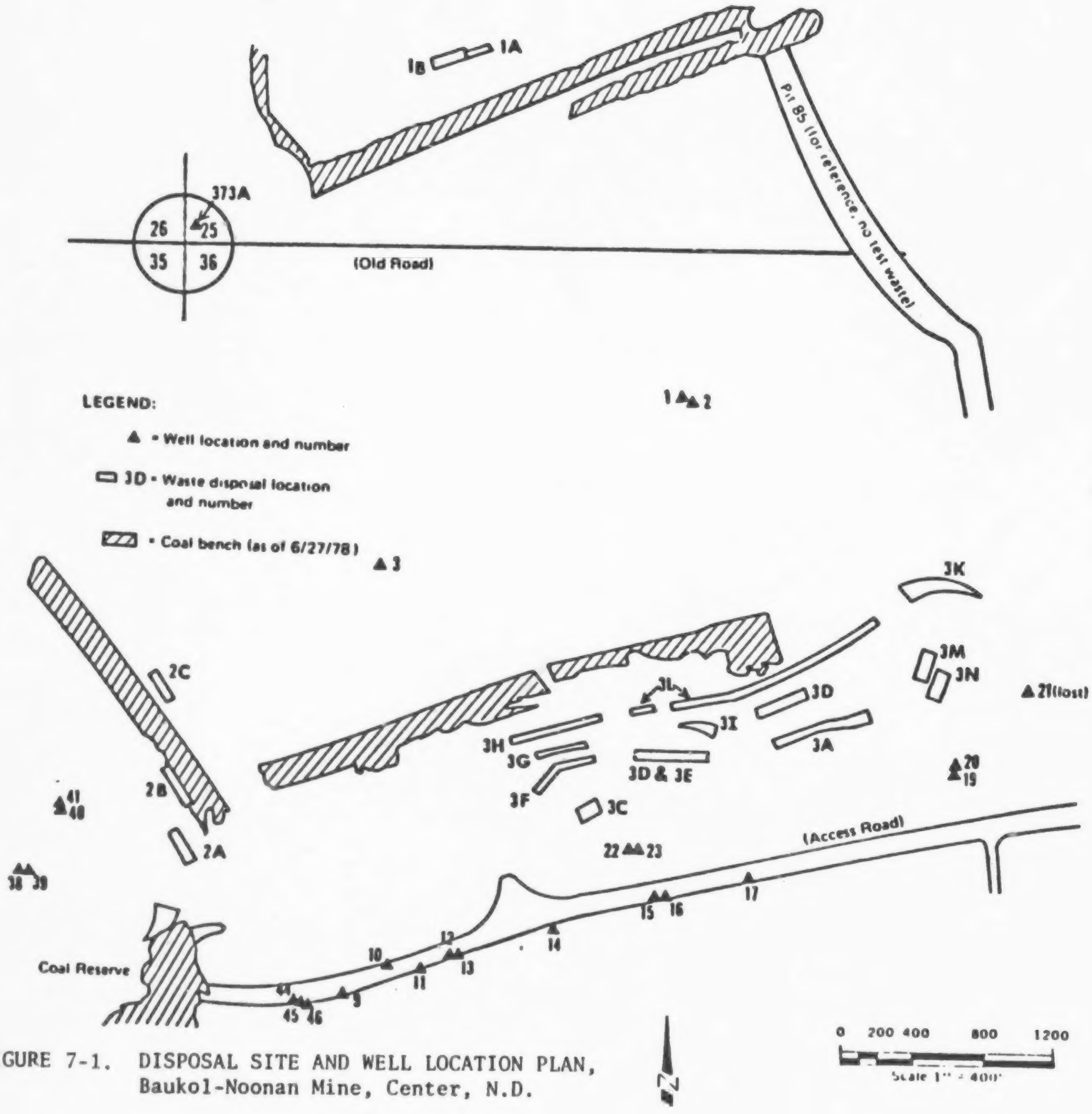
1B
1A
373A
26
25
35
36
(Old Road)
Pit 85 (for reference, no test waste)
LEGEND:
▲ = Well location and number
▭ 3D = Waste disposal location and number
▨ = Coal bench (as of 6/27/78)
1
2
3
3K
3M
3N
21(lost)
2C
3L
3D
3I
3A
3H
3G
3D & 3E
20
19
41
40
2B
3F
3C
2A
22
23
(Access Road)
38
39
17
15
16
14
12
10
13
11
Coal Reserve
44
9
45
46
0
200
400
800
1200
Scale 1" = 400'
N

FIGURE 7-1. DISPOSAL SITE AND WELL LOCATION PLAN, Baukol-Noonan Mine, Center, N.D.

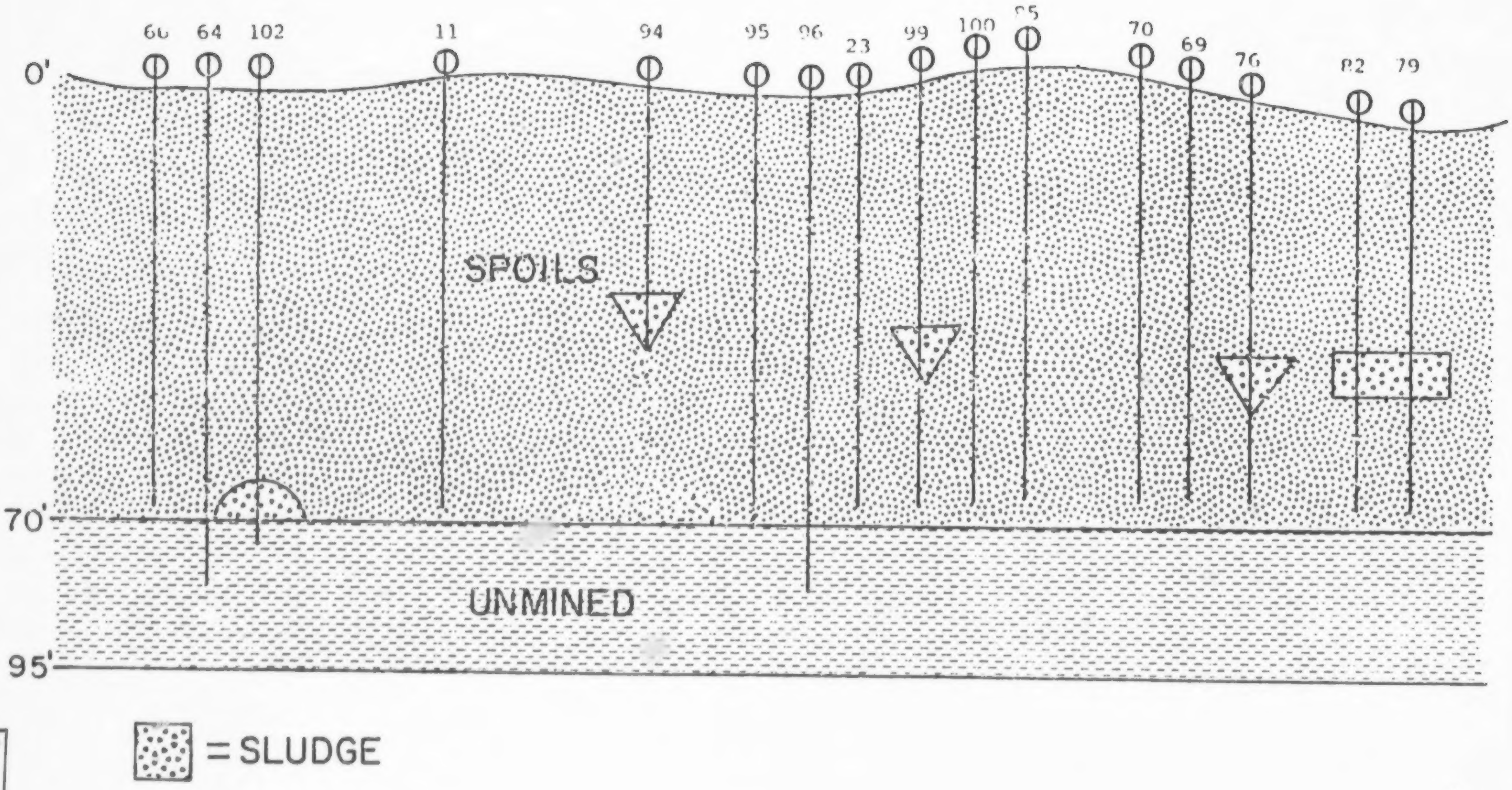
66
64
102
11
94
95
96
23
99
100
85
70
69
76
82
79
0'
SPOILS
70'
UNMINED
95'
= SLUDGE

FIGURE 7-2 STRATEGRAPHIC PLACEMENT OF POST RECLAMATION MONITORING WELLS IN VEES AND DRY PIT

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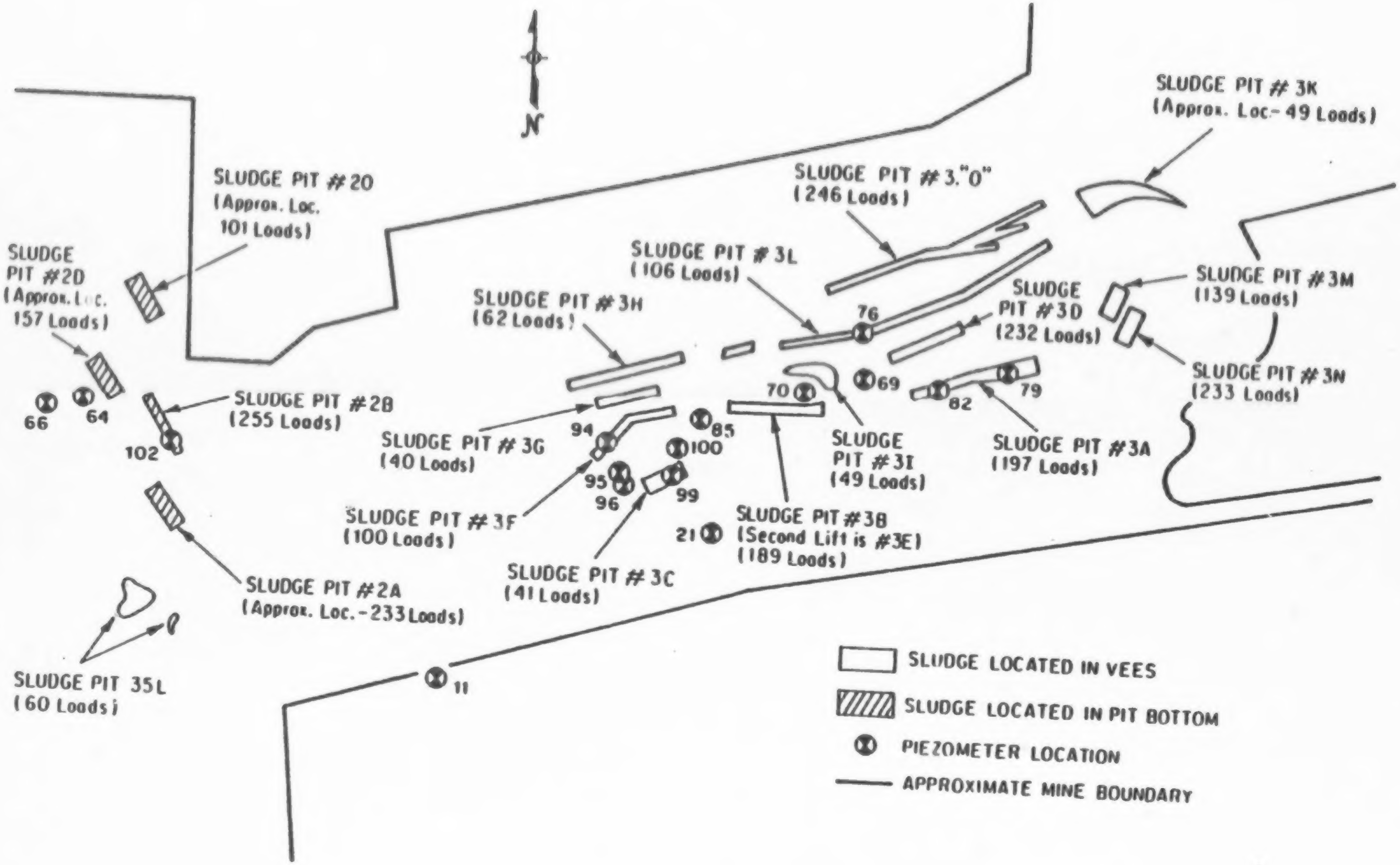
N
SLUDGE PIT # 3K (Approx. Loc.- 49 Loads)
SLUDGE PIT # 20 (Approx. Loc. 101 Loads)
SLUDGE PIT #2D (Approx. Loc. 157 Loads)
SLUDGE PIT # 3."0" (246 Loads)
SLUDGE PIT # 3L (106 Loads)
SLUDGE PIT # 3H (62 Loads)
SLUDGE PIT #3D (232 Loads)
SLUDGE PIT # 3M (139 Loads)
SLUDGE PIT # 3N (233 Loads)
SLUDGE PIT #2B (255 Loads)
SLUDGE PIT # 3G (40 Loads)
SLUDGE PIT #3I (49 Loads)
SLUDGE PIT # 3A (197 Loads)
SLUDGE PIT # 3F (100 Loads)
SLUDGE PIT #3B (Second Lift is #3E) (189 Loads)
SLUDGE PIT # 3C (41 Loads)
SLUDGE PIT #2A (Approx. Loc.-233 Loads)
SLUDGE PIT 35L (60 Loads)
66
64
102
76
70
69
82
79
94
85
100
95
96
99
21
11
SLUDGE LOCATED IN VEES
SLUDGE LOCATED IN PIT BOTTOM
PIEZOMETER LOCATION
APPROXIMATE MINE BOUNDARY

FIGURE 7-3. LOCATION OF GROUNDWATER AND LEACHATE WELLS INSTALLED AFTER SLUDGE DISPOSAL IN VEES AND DRY PITS.

lower concentrations of the same analytes. It may be argued that the sulfate and magnesium data for Well 76 are above the range for "spoils" wells shown in Table 7-5, and thus also tend to indicate that FGD-derived solutions have reached the screen area.

Well 102 is situated below one of the pit disposal areas, and it too, in comparison with the data shown in Table 7-5 for the region below the Hagel Bed, indicates the presence of FGD waste-derived liquor.

In attempting to employ the chemical analysis data, obtained for the large number of samples from the array of wells, as a means of estimating the extent to which FGD-derived substances may have been transported, one must consider the variability of the data (from natural or other causes).

For the compositional data summaries in Table 7-5, comparison of the standard deviation (i.e. a statistical measure of the spread of the data points) which the mean and the extreme values allows at least a qualitative judgment of the overall distribution of the data. The large number of samples, which were collected only every three to four months, result from the fact that samples from the range of seasons are included and averaged. (See Appendix B.)

Since the hydrologic interpretation suggests that the recharge of the spoils was occurring during the time frame in which these samples were taken and was apparently occurring by means of vertical infiltration, then it is reasonable to compare the results of the spoils samples to those from equivalent, unmined areas. Water from the lignite aquifers, particularly the Hagel Bed, is appropriate as a background reference point, since it is that (Hagel) water which has been displaced by the mining operation. Upon cessation of mining, spoils water will in time contact and, together with the unmined Hagel bed water, reform an aquifer continuum.

The data on the composition of FGD waste porewater and leachate from the column elution tests discussed in Section 7.3 indicated that contact with such wastes was likely to result in increased concentrations of major species including sulfate, sodium, magnesium and calcium in the receiving waters. However elutriation contact of groundwater with a number of the overburden materials found at the Center mine site likewise results in substantial increases in the concentrations of those same species, as shown by the data in Table 7-2. This variability and range in the concentrations of these major species found in both waste- and soil-derived solutions is a hindrance to the detection of small differences in concentration such as might result from the mixing of small volumes of waste-derived liquors with a large volume of groundwater from "spoils".

Even with the compositional variability discussed above, the sampling and analysis results given in Tables 7-6 and 7-7 clearly indicate that FGD-derived leachate has appeared in a number of the wells which were deliberately placed near waste in both Vee and pit locations. Table 7-8 provides a summary of the chemical analyses and other parameters for these affected wells in addition to data for appropriate reference locations.

The data in Table 7-8 suggest a number of relationships between FGD waste disposal conditions and observed water compositions in the affected wells. Data from the relevant laboratory tests is also consistent with these relationships.

- The concentrations of sulfate and magnesium found in the samples obtained thus far are substantially lower than the compositions of undiluted FGD waste purewater (Table 7-1). Sodium concentrations are also lower than purewater except in the pit bottom location (Well 102) where higher sodium and correspondingly lower magnesium concentrations may be

TABLE 7-8

PARAMETERS OF INTEREST FOR WELLS SHOWING EVIDENCE OF FGD-RELATED LEACHATE

Well No.	Waste/ Well Locations[1,3,5]	Date Sampled	Chemical Analysis Data[2] Analyte Concentration (mg/L) Sulfate	Sodium	Magnesium	Calcium	Approximate Dates[3] Waste Disposal	Over-burden Return
99	"Vee"-3C/ below waste	3/27/80	4111	960	530	215.5	10/78	5/79
		6/09/80	3811	1050	408	393		
		9/09/80	3500	776	457	331		
94	"Vee"-3F/ offset from waste	3/27/80	4917	900	615	195.3	11/78	5/79
		6/09/80	3572	493	262	307		
		9/09/80	4980	730	596	404		
79	"Vee"-3A/ below waste	6/09/80	1922	331	358	215	9/78	4/79
		9/09/80	2891	567	421	416		
102	pit bottom - 2B/below and offset from waste	3/27/80	1465	823	49.5	65.8	6/78	4/79
		6/09/80	4343	1845	105	186		
		9/09/80	5108	2200	151	560		
Data for Related Groundwater Wells -								
76	"Vee"-3L/ below waste?	6/09/80	222	322	34	65	3/79	5/79
		9/09/80	148	377	30	58		
Average of "spoils wells"[4]		1978-79	1455	361	232	348		
Average of "below Hagel" wells[4]		1978-79	1217	568	80.4	153		
Average of "Hagel Bed" wells[4]		1978-79	668	297	74.3	105		

[1] from Figure 7-2

[2] from Table 7-7

[3] from Table 6-3

[4] from Table 7-5

[5] from Table 7-6 and Figure 7-3

the result of ion exchange processes. Calcium appears to be under solubility control by sulfate. These data suggest two possible scenarios related to the FGD waste leaching: either the groundwater even in close proximity to the waste is a mixture of waste leachate and other infiltrating groundwater which bypassed or "channeled" through the waste; or the contact of infiltrating groundwater does not provide as efficient an extraction of solubles as predicted by the laboratory leaching column tests. While the cause cannot be ascertained with certainty, for Vee-notch disposal the net effect is the same, namely that such disposal may not result in the appearance of a "plug" of full-strength FGD-waste purewater in the groundwater. The data for the pit bottom placement location suggest that the leachate concentration (i.e. the fraction of leachate) is higher than for Vee-notch.

- The data for Vee-notch Wells 99 and 94 suggest that for those two wells, the concentrations of FGD-waste derived species may already have peaked or be near peak subject to seasonable fluctuations (Well 94). In both wells, sodium and magnesium concentrations have decreased, and calcium has increased consistent with the leaching column results, and hydrogeochemical conclusions reached in the UND Report.

- The data for Well 79 suggests that the FGD-waste related impacts which are, or will be, seen at that well are less than those observed at Wells 99 and 94. Alternatively, the FGD leachate could be delayed in reaching the Well 79 vicinity. Geohydrologic and other data were not available for that well at this time, but should become available from the UND team in the future.

- The absence, to date from Well 76 of FGD-related species which are present in water around Wells 99, 94 and 79 may be due to at least three possible factors, any or all of which may be operative:

- The well was located much farther from an FGD leachate source than were the other three wells;
- The waste in Pit 3L (Well 76) was placed several months after the other locations, and insufficient time had elapsed for leaching; or
- The waste in Pit 3L was covered (i.e., the overburden was returned) almost immediately after disposal while for the other monitoring well locations, the delay was some 6 to 7 months long during which time the waste was exposed to weathering, precipitation and freeze-thaw effects.

- The data for the pit bottom waste placement (Well 102) suggest and are consistent with a number of interesting findings.
  - The concentrations of FGD-leachate major species continually increase over the sampling period indicating continued formation (or arrival) of leachate.
  - The sodium/magnesium ratio in all samples is consistent with that found in the "Below Hagel Bed" stratum rather that with the "Spoils" or "Hazel Bed" water compositions shown in Table 6-5. This is quite different from the Vee-placement liquors, and suggests that the leachate may have been subjected to some ion exchange processes prior to reaching the well.
  - The FGD-related species are apparently just appearing at the well, since the 3-27-80 analyses are quite consistent with the composition of the "Sand 5M Below Hazel Bed" stratum, The 6-9-80 data then clearly reflect the presence of FGD leachate.

  - The concentrations of sulfate and sodium (which presumably occurs because of ion-exchange phenomena) by 9-9-80 apparently result in an increased calcium concentration, due to ionic strength and ion-pair formation reactions. The assumption is made that the waste disposed in Pit 2B (pit bottom disposal) is of the same quality (i.e. not low magnesium, high sodium, high lime) as was placed in the Vee-notch test areas. Comparison of these water composition data from Well 102 with the range of FGD-waste purewater compositions in Table 6-1 suggests that the high sodium/magnesium ratio is likely the result of some geochemical processes which may arise from the nature of the spoils in the area as well as the well stratum composition.
  - Pit bottom 2B, where well 102 is located, was reportedly not completely reclaimed for almost one year during at least a portion of which time the wastes were subjected to some or all of the yearly fluctuations in precipitation and temperature. Such exposure might well have resulted in rapid initial extraction/leaching of solubles by accumulating and percolating surface runoff, for example.

- Both the laboratory predictive tests and the field data indicate that placement of these FGD wastes from alkaline FGD systems will result in generation of liquors and leachates which show increased concentrations of sulfate, sodium, magnesium and, to some extent, calcium. Of these the sulfate (and consequently, total dissolved solids) will be substantially above drinking water limits (250 mg/L and 10,000 mg/L respectively).

- Laboratory predictive tests and field test results indicate that for FGD wastes trace elements in leachates are likely to be within the allowable range for drinking water.

In agreement with the UND Report, the data indicate that the major impact on groundwater from the alkaline fly ash FGD wastes generated at the M.R. Young plant will stem from the high concentations of sulfate, and those portions of other major species which contribute to the dissolved solids. These TDS contributors are present in the wastes as soluble species readily available for leaching.

Comparison of FGD and Fly Ash Waste Properties and Effects

The UND investigation focused a significant portion of their effort on characterization and elucidation of some of the effects relating to the disposal of alkaline fly ash itself. This phase of their investigation resulted upon the realization that, in the absence of a working FGD system, the alkaline ash in excess of that which could be used (and/or sold for use) in cements or other building materials was disposed in mine in the same manner as the FGD wastes.

In contrast to FGD wastes, alkaline fly ash has a rather significant potential to impact the environment as shown by the data in Tables 7-3, 7-4 and 7-6. The principal environmental impacts are attributed to high pH, excessive trace metals including arsenic, selenium, molybdenium and lead, as well as high sulfate and TDS levels. Neutralization of the alkalinity i.e., the use of the ash in acid neutralization/scrubbing process, will reduce the toxicity of the fly ash to such a degree as to make disposal an acceptable process, when done with appropriate attention toward minimizing leaching of solubles.

To summarize the results of these tests, Appendix E (p. E-33). concludes:

> "These data indicate, as suggested by laboratory studies, that the major potential impact on groundwater of FGD waste from the Milton R. Young plant is the generation of exceptionally high concentrations of sulfate and other major ions. The generation of these ions in solution, as previously discussed is largely dependent upon the dissolution of soluble salts. Therefore, these impacts can be minimized by the design and selection of disposal sites which isolate the FGD waste from infiltrating water."

It would appear that the term "exceptionally high" to describe concentrations of sulfate is not being fully justified, since the filed data indicate that the sulfate levels measured near the waste with little opportunity for additional dilution are only some 2-3 times those found in the mine spoils water itself. Considerations, outside of the current context, will have to be given to the effects of the mining operation itself on the environment. Appendix E (pg E-34) indicates:

> "Although the primary purpose of fly-ash-type flue gas desulfurization systems is to reduce atmospheric contamination, the results of this study show that a seondary benefit of this method of flue-gas processing is the conversion of fly ash from a form that can cause groundwater to acquire severe toxicity because of high arsenic and selenium levels to a waste form that causes increased sulfate concentrations but generally no significant increases in the more toxic elements.
>
> Burial of FGD waste in mined areas offers an effective means of disposing of this waste, providing that the waste is placed in favorable locations in the mined area and provided that the selective placement of the waste and spoil is accomplished with appropriate consideration for the hydrologic and geochemical nature of the systems.
>
> Placement of these wastes in V-notch settings appears to be highly preferable to pit bottom disposal in most areas. V-notch areas are commonly above the postmining water table, and thus offer much less opportunity for the dissolution and leaching of soluble salts present in these waste products. Ongoing research will better evaluate the suitability of various postmining landscape positions for the disposal of fly ash and fly ash FGD waste."

8.0 ENGINEERING/COST ASSESSMENT

8.1 Introduction

Conceptual type cost estimates (±30%) were developed for both the original (ceased operation in November 1981) and currently operating fly ash and FGD waste handling/processing/disposal systems at the Milton R. Young plant of Minnkotat Power Cooperative, Inc. The plant, located in Center, North Dakota, has a total nameplate generating capacity of 741 mw. Of interest to us in this program are the two waste processing/disposal systems handling the combined fly ash/FGD waste generated from the two flue gas desulfurization (FGD) spray towers on Unit 2 (476 Mw) and the fly ash from Unit 1 (265 Mw). The fly ash from Unit 1 is of interest because it is this fly ash, along with that produced from Unit 2, that is employed in the lime/alkaline fly ash scrubbing operations servicing Unit 2.

8.2 Process Description

8.2.1 Original Waste Disposal Scheme

The original waste handling/processing/disposal system which was in operating for about four years at the Milton R. Young plant consisted of thickening and vacuum filtering the fly ash/FGD scrubber effluents from about 15 wt% solids to about 65 wt% solids (Figure 8-1). From the vacuum filter, the 65 wt% fly ash/FGD waste was directed by belt conveyor to one of two surge bins. The surge bins acted as temporary storage for the waste until it was loaded onto 35-ton coal haul trucks. These trucks transported the waste to the Baukol-Noonan, Inc., Center Mine which is located about five miles from the plant. At the mine, the waste was deposited as a relatively dry soil-like material in either: (a) the pit bottom prior to the return of overburden; (b) the spoil banks (vee-notches) before rough contouring.

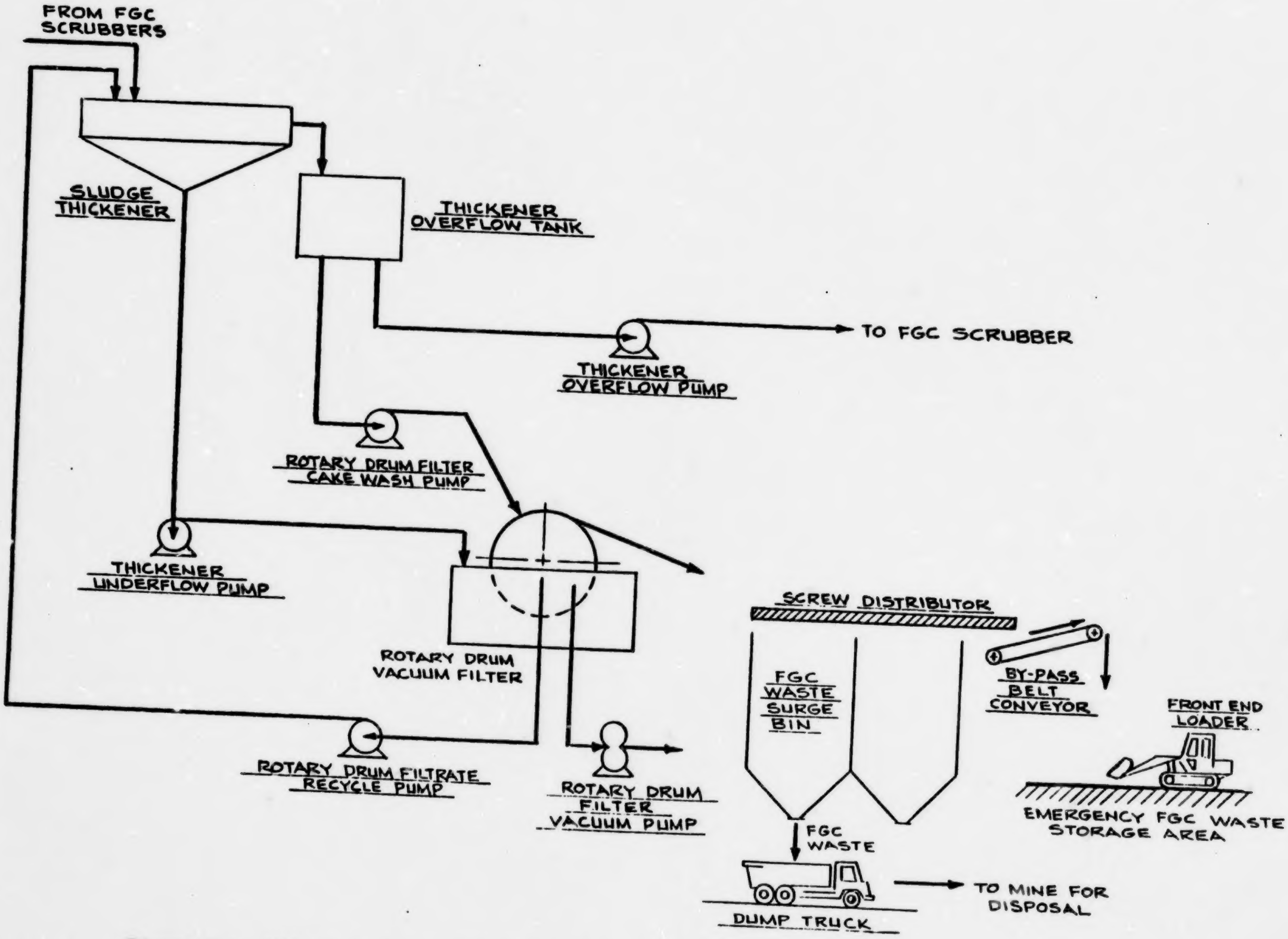
FROM FGC SCRUBBERS
SLUDGE THICKENER
THICKENER OVERFLOW TANK
TO FGC SCRUBBER
THICKENER OVERFLOW PUMP
ROTARY DRUM FILTER CAKE WASH PUMP
THICKENER UNDERFLOW PUMP
ROTARY DRUM VACUUM FILTER
ROTARY DRUM FILTRATE RECYCLE PUMP
ROTARY DRUM FILTER VACUUM PUMP
SCREW DISTRIBUTOR
FGC WASTE SURGE BIN
BY-PASS BELT CONVEYOR
FRONT END LOADER
EMERGENCY FGC WASTE STORAGE AREA
FGC WASTE
DUMP TRUCK
TO MINE FOR DISPOSAL

Figure 8-1 Milton R. Young FGC Waste Processing/Interim Storage/Transport Schematic Flow Diagram (Original Scheme as of 1977-1978).

Reference: (11)

The major items of equipment along with their quantity and specifications are summarized in Table 8.1. The equipment items are listed under one of two subcategories: (1) handling/processing/storage; and (2) transportation/placement/disposal. The first category contains all stationary process equipment while the latter contains only mobile equipment.

This waste disposal scheme began operations in September 1977 when the FGD system started up, however, the waste processing operations seemed to be constantly plagued by problems. The plant reports that one of the more frequent problems was thickener breakdown due to the buildup of coarse solids in the thickener. As a result, controlling the wt% solids in the thickener underflow being directed to the vacuum filter was difficult at best. This eventually led to poor vacuum filter performance, inadequate dewatering and a hard-to-handle waste. Consequently, the plant decided to retire the thickener and vacuum filter operations and, instead, direct the scrubber effluent to settling ponds to achieve the necessary dewatering. This interim pond/mine disposal scheme has been in operation since November 1981.

8.2.2 Current Waste Disposal Scheme

Figure 8.2 depicts the current waste disposal scheme which involves scrubber effluent consisting of fly ash and FGD waste being discharged to a blowdown sump and then pumped to one of two settling ponds. The settling ponds provide interim storage for the waste while it dewaters, and clarified water (pond overflow) is returned to the FGD system. After a pond has reached its design storage capacity (approximately once every six months), the fly ash/FGD waste would be directed to the other settling pond. The remaining water in the full pond would then be drawn off, the pond dredged and the dewatered fly ash/FGD waste (approximately 65 wt% solids) loaded onto 35-ton trucks and hauled to the Baukol-Noonan, Inc., Center Mine. The distance form the settling ponds to the mine is about five miles. As in the original waste disposal scheme, the waste is deposited as a relatively dry soil-like material in either the pit bottom or spoil banks (vee-notches).

TABLE 8.1

MAJOR EQUIPMENT ITEMS/SPECIFICATIONS/COST

(Original Scheme - Thickener/Vacuum Filter/Mine)

Quantity	Item	Description
Handling/Processing/Storage		
1	Thickener (incl. rake and motor)	130' dia. x 21-1/2' ht. (12' ht. conical portion); concrete
2	Thickener Underflow Pump	445 gpm, 74' TDH, 25 HP
1	Thickener Overflow Tank	12' dia. x 15' ht.; mild steel
2	Thickener Overflow Pump	1112 gpm; 61' TDH; 40 HP
2	Rotary Drum Filter Cake Wash Pump	120 gpm; NA' TDH; 20 HP
2	Rotary Drum Vacuum Filter	12' dia. x 14' length; 528 ft^2; 15 HP; rotary drum type
2	Rotary Drum Vacuum Filtrate Recycle Pump	328 gpm; 60' TDH; 15 HP
2	Rotary Drum Filter Vacuum Pump	2900 cfm; 20" Hg; 200 HP
6	Screw Distributor	40 HP; 3/surge bin
2	Surge Bin	8' x 8' x 12'; mild steel
1	By-Pass Belt Conveyor	18" wide; 100' length; 15 HP
Transportation/Placement/Disposal		
3	Dump Truck	30 cy; 35 ton; 415 HP; heated box
1	Wheel Loader	100 HP; 1-1/2 cy bucket
2	Wheel Dozer	575 HP; 7' x 20' blade/375 HP; 4' x 16' blade
2	Bull Dozer	410 HP; NA ' blade; track type
1	Motor Grader	180 HP; 14' blade

Reference (11)

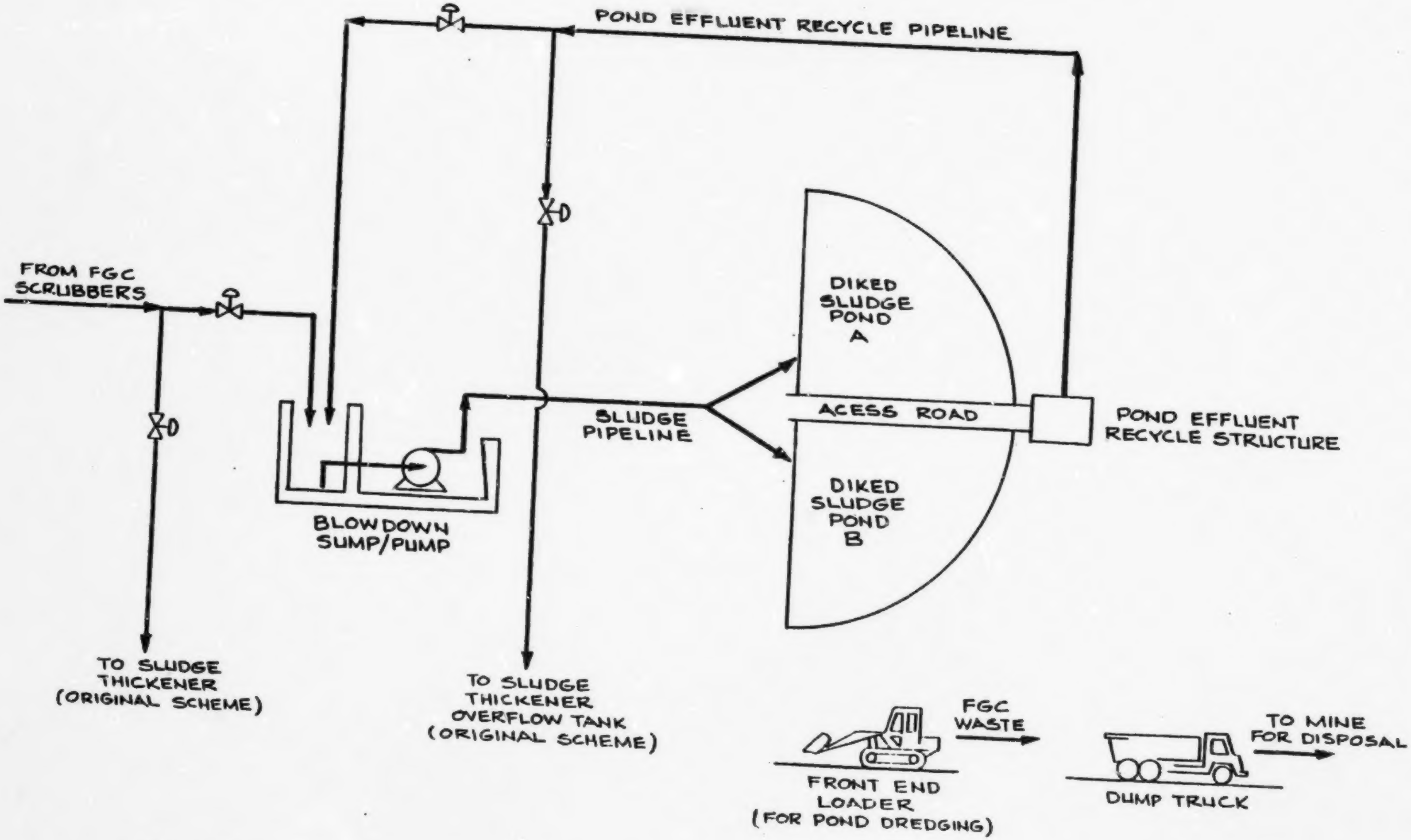
POND EFFLUENT RECYCLE PIPELINE
FROM FGC SCRUBBERS
TO SLUDGE THICKENER (ORIGINAL SCHEME)
BLOWDOWN SUMP/PUMP
TO SLUDGE THICKENER OVERFLOW TANK (ORIGINAL SCHEME)
SLUDGE PIPELINE
DIKED SLUDGE POND A
ACESS ROAD
DIKED SLUDGE POND B
POND EFFLUENT RECYCLE STRUCTURE
FGC WASTE
FRONT END LOADER (FOR POND DREDGING)
DUMP TRUCK
TO MINE FOR DISPOSAL

Figure 8-2 Milton R. Young FGC Waste Handling/Interim Storage/Transport Schematic Flow Diagram (Process as of 1980-1981)

Reference: (11)

8.3 Capital Cost Estimates

Capital costs for the vee-notch disposal of alkaline fly ash/FGD waste are presented in Tables 8.2 and 8.3 for both the original and currently operating waste disposal schemes, respectively, at the Milton R. Young plant. The battery limits for both schemes begin at the scrubber discharge and go to and include the actual placement of the waste in the mine. Both waste disposal schemes are assumed to handle the combined fly ash/FGD waste generated from Unit 2 (476 Mw) and fly ash from Unit 7 (265 Mw) at a 90% load factor. The conceptual type capital cost estimates (±30%) are based primarily on actual plant invoices, along with a process description, flow sheet, material balance, equipment list and equipment specifications.

The total capital investment estimates for both process equipment and settling ponds consist of direct capital investment for equipment, its installation and its service facilities and indirect capital investment for engineering and design, architect and engineering contracting, contracting fees and the cost of funds during construction. For the process equipment in the original waste disposal scheme, direct capital investment costs were based on 1978 cost data supplied by the plant, which was escalated (9%/year) to late 1981 dollars. Process equipment and settling pond cost data, for the current waste disposal scheme, is based on 1981 cost data furnished by the plant. The cost for land and working capital, however, are not included in these estimates. Capital cost estimates for mobile equipment are based both on 1981 cost data supplied by manufacturers and cost data found in the literature.

TABLE 8.2

MAJOR EQUIPMENT ITEM COSTS
(Original Scheme - Thickener/Vacuum Filter/Mine)

Quantity	Item	Total Capital Cost (1981 $)
Handling/Processing/Storage		
1	Thickener (incl. rake and motor)	$3,800 \times 10^3$
2	Thickener Underflow Pump	
1	Thickener Overflow Tank	
2	Thickener Overflow Pump	
2	Rotary Drum Filter Cake Wash Pump	$4,900 \times 10^3$
2	Rotary Drum Vacuum Filter	
2	Rotary Drum Vacuum Filtrate Recycle Pump	
2	Rotary Drum Filter Vacuum Pump	
6	Screw Distributor	$1,300 \times 10^3$
2	Surge Bin	
1	By-pass Belt Conveyor	
Total		$10,000 \times 10^3$ (a)
Transportation/Placement/Disposal		
1	Dump Truck	350×10^3
1	Wheel Loader	100×10^3
2	Wheel Dozer	400×10^3
2	Bull Dozer	----
1	Motor Grader	----
Total		850×10^3 (b)

(a) Excludes costs associated with scrubber modifications which had to be made no matter which of the two operating schemes are employed.

(b) Excludes costs associated with bulldozers and motor grader since they are not dedicated entirely to FCC waste disposal.

Reference: (11)

TABLE 8.3

MAJOR EQUIPMENT ITEM COSTS
(Current Scheme - Interim Settling Ponds/Mine)

Quantity	Item	Total Capital Cost (1981 $)
Handling/Processing/Storage/Dredging		
1	Blowdown Sump	$1,300 \times 10^3$
2	Blowdown Sump Pump	
1	Access Road	$2,300 \times 10^3$
2	Sludge Pond	
2	Sludge Pipeline	400×10^3
1	Pond Effluent Recycle Structure	
1	Pond Effluent Recycle Pipeline	
3	Dredging Equipment Front-end Loader	500×10^3
Total		$4,500 \times 10^3$ (a)
Transportation/Placement/Disposal		
3	Dump Truck	350×10^3
1	Wheel Loader	100×10^3
2	Wheel Dozer	400×10^3
2	Bull Dozer	----
1	Motor Grader	----
Total		850×10^3 (b)

(a) Excludes costs associated with scrubber modifications which had to be made no matter which of the two operating schemes are employed.

(b) Excludes costs associated with bulldozers and motor grader since they are not dedicated entirely to FGC waste disposal.

Reference: (11)

As and when one compares Tables 8.2 and 8.3, the total capital cost for waste handling/processing/storage in the original scheme is more than twice that for the current scheme. The difference is primarily due to the more expensive waste processing equipment (thickener and vacuum filter) found in the original scheme as compared to the lower cost waste processing (settling pond) found in the current disposal scheme. With respect to the capital costs associated with the transportation/placement/disposal of FGC wastes in the two disposal schemes, Table 8.2 and 8.3 indicate that no difference exists. This is due to the fact that the same type of quantity of mobile equipment is required for both schemes, regardless of the differences in the waste processing operations.

8.4 Operating Cost Estimates

The overall basis for estimating operating costs is presented in Table 8.4 and represents the average conditions at this plant. The annual operating cost estimates for both old and current waste disposal scenarios were made on the basis of each scenario handling the total fly ash/FGD waste output of Unit 2 (476 Mw) and fly ash from Unit 1 (265 Mw) at 90% load factor. Coal ash and sulfur content were fixed at 9.74% and 0.64% respectively. Based on these, the operating capacity for each of the two waste disposal schemes is 313,000 tons waste per year. Of this total waste quantity, fly ash/FGD accounts for 65 wt% while water accounts for the remaining 35 wt%.

Table 8.5 summarizes the major cost elements contributing to the annual operating costs for both the original and current waste disposal schemes. For the most part, within the accuracy of our estimates, the percent of the total annual operating cost due to direct costs (labor, maintenance and utilities) and indirect costs (plant/administrative overhead and capital charges) for both systems are about the same; a 35-40%/65-60% split, respectively. In comparing the individual elements making up the direct and indirect costs for each of two schemes, it becomes apparent that the capital charges (taken as 16.5% of the total capital cost) in the original scheme

TABLE 8.4

WASTE DISPOSAL ENGINEERING OPERATING BASIS

MILTON R. YOUNG (UNIT 2)

Boiler	
Capacity (Mw):	476
Annual Load Factor (%):	90
Heat Rate (Btu/kwh):	10,000
Fly Ash/Bottom Ash Ratio:	35/65
Coal	
HHV (Btu/lb):	6,422
Sulfur Content (%):	.64
Ash Content (%):	9.74
Emission Control	
SO_2 Removal (%):	60
Particulate Removal (%):	99+
Wastes Generated	
Fly Ash[a] (tons/yr):	157,300
FGD Sludge (tons/yr):	58,475
Total FGD Waste (tons/yr):	215,775 (dry basis)
Total FGD Waste (tons/yr):	332,000 (wet basis)

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[a] Includes fly ash from Unit 1 and Unit 2, since fly ash from Unit 1 is used in alkaline fly ash scrubbing operation. Capacity of Unit 1 is 265 Mw.

Reference: (11) and Arthur D. Little Estimate

TABLE 8.5

ANNUAL OPERATING COST SUMMARY
(1981 Dollars)

	($1000) Original Disposal Scheme[a]	($1000) Current Disposal Scheme[b]
DIRECT COSTS		
• Operating/Supervisory Labor	$417.2	$495.8
• Maintenance (Labor and Materials)	354.0	214.0
• Utilities		
- Water (@ $.01/k gal)	.3	.3
- Electricity (@ $.03/kwh)	156.0	54.0
- Diesel Fuel (@ $.95/gal)	255.7	332.4
INDIRECT COSTS		
• Plant Overhead (@ 50% Direct Costs minus Electricity)	513.6	521.3
• Administrative Overhead (@ 10% Total Labor Cost)	59.4	60.3
• Capital Charges (@ 16.5% of Total Capital Cost)	1798.5	891.0
TOTAL ANNUAL OPERATING COST		
• ($1000 $/year)	$3554.7	$2570.1
• ($/ton)	$ 10.70	$ 7.75

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[a] Thickening/Vacuum Filtration/Mine Disposal Scheme - Milton R. Young (Unit 2)
[b] Interim Ponding/Mine Disposal Scheme - Milton R. Young (Unit 2)

Reference: (11) and Arthur D. Little Estimates account for over 50% of the total operating cost while in the current scheme capital charges account for less than 35% of the total. Consequently, the original scheme appear to be considerably more capital intensive. Additionally, the original scheme is more maintenance (including both labor and materials) intensive. This is due to the fact that the original scheme includes considerably more process equipment: a thickener and two vacuum filters, in contrast to lower maintenance cost items in the current scheme - two settling ponds. The bottom line of all this is that the annual operating cost of the original scheme is nearly 40% greater ($10.70/ton) than that of the current scheme ($7.75/ton).

It is important to note, however, that to date neither of the two interim settling ponds in the current waste disposal scheme have been dredged. Consequently, there is no actual data available from the plant on either the type of equipment or method of dredging to be employed or any operating cost data. Based on discussions with plant personnel,however, it was assumed that once a settling pond has reached its storage capacity, the remaining water would be drawn off and the pond dredged. It is assumed (in preparing these operating cost estimates) that the fly ash/FGD waste will dewater to such an extent as to allow for front end loaders to drive into the ponds and carry on dredging operations. Dredging operations will cease when the front end loaders strike bottom ash, which was placed across the bottom of the pond during pond construction. Approximately two feet of bottom ash was placed to both protect the clay liner from damage during dredging operations, and to assist in waste dewatering. The two-foot layer of bottom ash acts as a drainage bed.

8.5 Comparison of Projected Costs for Mine Disposal with Those for Other Disposal Modes

A number of conceptual design and cost studies have been undertaken sponsored by governmental agencies and private organizations, notably the EPA and EPRI. These studies have been basically of two types: (1) generalized costing to develop comparative economics for various waste disposal options, including current practices and potential alternatives;

and (2) economic impact analyses to estimate the effects of various FGC waste disposal regulatory scenarios on the utility industry. Unfortunately, however, the design and operating assumptions in these economic studies, as well as the battery limits for the disposal systems, differ. Also, costs are generally presented in lump sum form covering both the waste processing and disposal facilities. Hence, direct comparisons of cost estimates are difficult at best.

In light of all this, the comparison that can be made between the surface mine waste disposal costs reported herein and other type waste disposal cost is a generalized one. For example: for the handling, processing (thickening and vacuum filtration) and transport of a combined fly ash/FGD waste for placement in a mine at the Milton R. Young plant, the annual operating cost is estimated at $10.70/ton; while for the same waste handling, processing and transport, but placement in a managed landfill, the annual operating cost would be (within the accuracy of these estimates) roughly 20-25% higher due to higher land and mobile equipment capital costs and increased disposal labor and mobile equipment operating costs. Higher operating costs for a managed landfill are partly due to the fact that with a landfill there are reclamation costs while reclamation is a normal part of mine operations. From both the capital and operating cost viewpoint, mine disposal appears to be an attractive option.

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APPENDIX A

Design and Performance Data on Milton R. Young Station Unit No. 2

Reference: (5)

SECTION 3
DESIGN AND PERFORMANCE DATA FOR OPERATIONAL DOMESTIC FGD SYSTEMS

COMPANY NAME	MINNKOTA POWER COOPERATIVE	
PLANT NAME	MILTON R. YOUNG	
UNIT NUMBER	2	
CITY	CENTER	
STATE	NORTH DAKOTA	
REGULATORY CLASSIFICATION	D	
PARTICULATE EMISSION LIMITATION - NG/J	43.	(.100 LB/MMBTU)
SO2 EMISSION LIMITATION - NG/J	516.	(1.200 LB/MMBTU)
NOX EMISSION LIMITATION - NG/J	******	(****** LB/MMBTU)
NET PLANT GENERATING CAPACITY - MW	690	
GROSS UNIT GENERATING CAPACITY - MW	440	
NET UNIT GENERATING CAPACITY W/FGD - MW	402	
NET UNIT GENERATING CAPACITY WO/FGD - MW	409	
EQUIVALENT SCRUBBED CAPACITY - MW	185	
** UNIT DATA - BOILER AND STACK		
BOILER SUPPLIER	BABCOCK & WILCOX	
BOILER TYPE	CYCLONE	
BOILER SERVICE LOAD	BASE	
DESIGN BOILER FLUE GAS FLOW - CU.M/S	953.90	(2021400 ACFM)
BOILER FLUE GAS TEMPERATURE - C	179.4	(355 F)
STACK HEIGHT - M	168.	(550 FT)
STACK SHELL	CONCRETE	
STACK TOP DIAMETER - M	7.6	(25.0 FT)
** FUEL DATA		
FUEL TYPE	COAL	
FUEL GRADE	LIGNITE	
AVERAGE HEAT CONTENT - J/G	15119.	(6500 BTU/LB)
RANGE HEAT CONTENT - BTU/LB		5800-7200
AVERAGE ASH CONTENT - %	6.50	
RANGE ASH CONTENT - %	5-8	
AVERAGE MOISTURE CONTENT - %	38.00	
RANGE MOISTURE CONTENT - %	32-43	
AVERAGE SULFUR CONTENT - %	.70	
RANGE SULFUR CONTENT - %	.35-1.3	
AVERAGE CHLORIDE CONTENT - %	.01	
RANGE CHLORIDE CONTENT - %	******	
*** PARTICLE CONTROL		
** FABRIC FILTER		
NUMBER	2	
** ESP		
NUMBER	2	
TYPE	COLD SIDE	
SUPPLIER	WHEELABRATOR-FRYE	
INLET FLUE GAS CAPACITY - CU.M/S	1038.2	(2200000 ACFM)
INLET FLUE GAS TEMPERATURE - C	193.3	(380 F)
PRESSURE DROP - KPA	.1	(1. IN-H2O)
PARTICLE REMOVAL EFFICENCY - %	99.6	
** PARTICLE SCRUBBER		
GENERIC TYPE	NONE	
SPECIFIC TYPE	N/A	
*** FGD SYSTEM		
** GENERAL DATA		
SALEABLE PPODUCT/THROWAWAY PRODUCT	THROWAWAY PRODUCT	
SO2 REMOVAL MODE	WET SCRUBBING	
PROCESS TYPE	LIME/ALKALINE FLYASH	
PROCESS ADDITIVES	NONE	
SYSTEM SUPPLIER	COMBUSTION EQUIP ASSOCIATES	
A-E FIRM	SANDERSON & PORTER	
DEVELOPMENT LEVEL	FULL SCALE	
NEW/RETROFIT	NEW	
UNIT DESIGN PARTICLE REMOVAL EFFICIENCY - %	99.60	

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MINNKOTA POWER COOPERATIVE: MILTON R. YOUNG 2 (CONT.)

UNIT DESIGN SO2 REMOVAL EFFICIENCY - %	36.13	
CURRENT STATUS	1	
COMMERCIAL START-UP	6/78	
INITIAL START-UP	9/77	
CONTRACT AWARDED	4/75	

** DESIGN AND OPERATING PARAMETERS

** ABSORBER

NUMBER	2	
NUMBER OF SPARES	1	
GENERIC TYPE	SPRAY TOWER	
SPECIFIC TYPE	OPEN COUNTERCURRENT SPRAY	
SUPPLIER	COMBUSTION EQUIP ASSOCIATES	
DIMENSIONS - FT	40 DIA X 120	
SHELL GENERIC MATERIAL	CARBON STEEL	
SHELL SPECIFIC MATERIAL	AISI 1110	
SHELL MATERIAL TRADE NAME/COMMON TYPE	N/A	
LINER GENERIC MATERIAL	ORGANIC	
LINER MATERIAL TRADE NAME/COMMON TYPE	FLAKEGLASS	
NUMBER OF CONTACTING ZONES	6	
LIQUID RECIRCULATION RATE - LITER/S	2740.	(43500 GPM)
L/G RATIO - L/CU.M	10.7	(80.0 GAL/1000 ACF)
GAS-SIDE PRESSURE DROP - KPA	2.0	(8.0 IN-H2O)
SUPERFICAL GAS VELOCITY - M/SEC	2.8	(9.1 FT/S)
INLET GAS FLOW - CU. M/S	405.36	(859000 ACFM)
INLET GAS TEMPERATURE - C	168.3	(335 F)
SO2 REMOVAL EFFICIENCY - %	85.0	
PARTICLE REMOVAL EFFICENCY - %	70.0	

** MIST ELIMINATOR

PRE-MIST ELIMINATOR/MIST ELIMINATOR	MIST ELIMINATOR	
NUMBER PER SYSTEM	2	
GENERIC TYPE	IMPINGEMENT	
SPECIFIC TYPE	BAFFLE	
TRADE NAME/COMMON TYPE	CHEVRON VANE	
CONFIGURATION	HORIZONTAL	
NUMBER OF STAGES	1	
NUMBER OF PASSES PER STAGE	4	
FREEBOARD DISTANCE - M	2.44	(8.0 FT)
DISTANCE BETWEEN STAGES - CM	5.08	(2.0 IN)
PRESSURE DROP - KPA	.2	(1.0 IN-H2O)
SUPERFICAL GAS VELOCITY - M/S	2.8	(9.1 FT/S)
CONSTRUCTION MATERIAL GENERIC TYPE	FLAKELINED 316L SS	
CONSTRUCTION MATERIAL SPECIFIC TYPE	POLYETHELYNE	
WASH WATER SOURCE	PART FRESH - PART TRAY	
WASH RATE - L/S	44.2	(700 GAL/MIN)

** REHEATER

NUMBER	2	
GENERIC TYPE	BYPASS	
SPECIFIC TYPE	COLD SIDE	
TRADE NAME/COMMON TYPE	N/A	
PERCENT GAS BYPASSED - AVG	15.0	
TEMPERATURE INCREASE - C	4.4	(40 F)
INLET FLUE GAS FLOW RATE - CU. M/S	70.78	(150000 ACFM)
INLET FLUE GAS TEMPERATURE - C	176.7	(350 F)
NUMBER OF TUBES PER BUNDLE	0	
CONSTRUCTION MATERIAL GENERIC TYPE	CARBON STEEL	

** FANS

NUMBER	2	
NUMBER OF SPARES	1	
SUPPLIER	BUFFALO FORGE	
FUNCTION	BOOSTER	
APPLICATION	BOILER ID, AXIAL	
SERVICE	DRY	
FLUE GAS FLOW RATE - CU.M/S	519.09	(1100000 ACFM)
FLUE GAS TEMPERATURE - C	176.7	(350 F)
CONSTRUCTION MATERIAL GENERIC TYPE	CARBON STEEL	

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EPA UTILITY FGD SURVEY: OCTOBER - DECEMBER 1980

MINNKOTA POWER COOPERATIVE: MILTON R. YOUNG 2 (CONT.)

  ** REAGENT PREPARATION EQUIPMENT
       FUNCTION                                  LIME SLAKING
       DEVICE                                    SLAKER
       MANUFACTURER                              WALLACE & TIERNAN
       NUMBER                                     1
       PRODUCT QUALITY - % SOLIDS                   12.0

  ** TANKS
       SERVICE                                   NUMBER
       -------                                   ------
       REACTION/RECYCLE                             2
       MIX TANK                                     1
       ******                                       4

  ** PUMPS
       SERVICE                                   NUMBER
       -------                                   ------
       ABSORBER RECIRCULATION                      10
       SPRAY RECIRCULATION                         10
       TRAY RECIRCULATION                           4
       TRAY SPRAY (CLARIFIER OVERFLOW)              2
       THICKENER UNDERFLOW                          2
       THICKENER OVERFLOW                           2
       LIME SLAKER TRANSFER                         2
       LIME SLURRY FEED                             2
       FLYASH SLURRY FEED                           2
       MIST ELIMINATOR SPRAY                        2

  ** SOLIDS CONCENTRATING/DEWATERING
       DEVICE                                    CENTRIFUGE
       NUMBER                                     2

  ** SOLIDS CONCENTRATING/DEWATERING
       DEVICE                                    THICKENER
       NUMBER                                     2
       SHELL SPECIFIC MATERIAL TYPE              CONCRETE
       FEED STREAM CHARACTERISTICS               12% SOLIDS
       OUTLET STREAM CHARACTERISTICS             40% SOLIDS

  ** SOLIDS CONCENTRATING/DEWATERING
       DEVICE                                    VACUUM FILTER
       NUMBER                                     2
       NUMBER OF SPARES                          0
       CAPACITY                                  750 TON/DAY
       SHELL GENERIC MATERIAL TYPE               MILD STEEL
       FEED STREAM CHARACTERISTICS               30% SOLIDS
       OUTLET STREAM CHARACTERISTICS             60% SOLIDS

*** SLUDGE

  ** DISPOSAL
       NATURE                                    FINAL
       TYPE                                      MINEFILL
       LOCATION                                  OFF SITE
       SITE TRANSPORTATION METHOD                TRUCK

  ** PROCESS CONTROL AND INSTRUMENTATION
       CHEMICAL PARAMETERS                       PH, SOLIDS
       CONTROL LEVELS                            SOLIDS 5.5-12%; PH 4.0-5.5
       PROCESS CONTROL MANNER                    MANUAL

  ** WATER BALANCE
       WATER LOOP TYPE                           CLOSED
       EVAPORATION WATER LOSS - LITER/S             34.6        (  550 GPM)
       MAKEUP WATER ADDITION - LITERS/S             44.1        (  700 GPM)
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MINNKOTA POWER COOPERATIVE: MILTON R. YOUNG 2 (CONT.)

** FGD SPARE CAPACITY INDICES

ABSORBER - %	100.0

** FGD SPARE COMPONENT INDICES

ABSORBER	1.0

PERFORMANCE DATA

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
0/77	SYSTEM										

** PROBLEMS/SOLUTIONS/COMMENTS

ALTHOUGH THE MILTON R YOUNG 2 SCRUBBING SYSTEM ORIGINAL DESIGN DID NOT INCLUDE SPARE FGD CAPACITY, THE SYSTEM DOES, IN ACTUALITY, GENERALLY HAVE A SPARE MODULE AS A CONSEQUENCE OF THE VARIABILITY IN LIGNITE SULFUR CONTENT. THE LIGNITE BLEND AT M.R.YOUNG 2 VARIES IN SULFUR CONTENT FROM 0.35 TO 1.3%. WHEN THE SULFUR CONTENT RISES TO 1.3% BOTH SCRUBBING TOWERS ARE REQUIRED (WITH 5 TO 15% OF THE FLUE GAS BYPASSED FOR REHEAT). WHEN THE SULFUR CONTENT DROPS TO 0.7% OR BELOW ONLY ONE TOWER IS REQUIRED. 0.7% SULFUR IS TYPICAL FOR THE M.R.YOUNG 2 LIGNITE BLEND. BECAUSE OF THE EFFECTIVE SPARE MODULE THE SYSTEM DEPENDABILITY FIGURES THAT APPEAR IN THIS SECTION WILL GENERALLY NOT BE EQUIVALENT TO THE AVERAGE OF THE MODULAR DEPENDABILITIES (E.G. WITH 0.7% SULFUR LIGNITE THERE IS 100% SPARE CAPACITY. IF A-MODULE OPERATES THE FIRST HALF OF THE MONTH (50%) AND B-MODULE THE SECOND HALF OF THE MONTH (50%) THE TOTAL SYSTEM UTILIZATION WILL BE 100%).

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
9/77	SYSTEM							720			

** PROBLEMS/SOLUTIONS/COMMENTS

INITIAL SCRUBBING OPERATIONS BEGAN IN SEPTEMBER. THE FGD SYSTEM IS EXPECTED TO BE OPERATING IN AN INTEGRATED MODE IN LATE OCTOBER, HOWEVER, A SCRUBBER LINING FAILURE MAY RESULT IN SOME DELAYS. THE UTILITY EXPECTS THE SYSTEM OPERATIONS TO STABILIZE BY MID-NOVEMBER.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
10/77	SYSTEM							744			
11/77	SYSTEM							720			

** PROBLEMS/SOLUTIONS/COMMENTS

THE UTILITY REPORTED INTERMITTENT FGD SYSTEM OPERATIONS SINCE START-UP.

MAJOR OPERATIONAL PROBLEMS HAVE OCCURRED AS A RESULT OF SEVERE WINTER WEATHER CONDITIONS, PARTICULARLY NUMEROUS INSTANCES OF FROZEN AND RUPTURED LINES. THE SYSTEM WAS SHUT DOWN DURING THE FIRST PART OF THE MONTH OF DECEMBER TO INSTALL HEAT TRACING IN THE LIQUID CIRCUIT.

SOME MINOR PROBLEMS HAVE OCCURRED WITH THE FLOW METERS (ROTAMETERS).

THE UTILITY ENCOUNTERED PROBLEMS WITH GUILLOTINE GAS DAMPER GUIDES DURING OCTOBER AND NOVEMBER.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
12/77	SYSTEM							744			

** PROBLEMS/SOLUTIONS/COMMENTS

THERE WAS AN EMERGENCY SHUTDOWN ON DECEMBER 5 AS A RESULT OF TURBINE BEARING DAMAGE. THE SHUTDOWN CONTINUED SO THAT A COMPLETE TURBINE INSPECTION COULD BE MADE.

WORK CONTINUED ON INSTALLATION OF ELECTRICAL HEAT TRACING ON SLURRY LINES AND WATER PIPING.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
1/78	SYSTEM							744			

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-----------------------------------------PERFORMANCE DATA--------------------------------------------------
PERIOD MODULE AVAILABILITY OPERABILITY RELIABILITY UTILIZATION  % REMOVAL   PER  BOILER  FGD   CAP.
------ ------ ------------ ----------- ----------- -----------  SO2  PART. HOURS HOURS HOURS FACTOR
                                                                ----- ----- ----- ------ ----- ------
        ** PROBLEMS/SOLUTIONS/COMMENTS

                              BECAUSE OF THE TURBINE BEARING PROBLEMS THE COMPLIANCE TEST ORIGINALLY
                              SCHEDULED FOR THE DECEMBER-JANUARY PERIOD WAS TENTATIVELY RESCHEDULED
                              WITH THE EPA FOR THE END OF MARCH.  THE UTILITY EXPECTS THE FGD SYSTEM TO
                              ACHIEVE EQUILIBRIUM (WATER BALANCE) WHEN THE UNIT COMES BACK ON LINE
                              IN FEBRUARY.

 2/78  SYSTEM                                                                 672

        ** PROBLEMS/SOLUTIONS/COMMENTS

                              BOTH THE BOILER AND FGD SYSTEM CAME BACK ON LINE FEBRUARY 21 AFTER COM-
                              PLETION OF THE TURBINE REPAIRS.  THE COMPLIANCE TEST HAS AGAIN BEEN RE-
                              SCHEDULED WITH EPA FOR THE END OF MAY.

                              ONE FORCED-DRAFT FAN (UPSTREAM OF THE FGD SYSTEM) HAD AN OIL LEAK AND A
                              SHAFT ALIGNMENT PROBLEM.  THE FAN WAS TAKEN OFF LINE AND SHIPPED TO
                              BUFFALO FORGE FOR REPAIRS.

                              THE VACUUM FILTER MALFUNCTIONED, ALLOWING LARGER SIZE PARTICLES TO ESCAPE
                              THE FILTER.  THIS CAUSED THE RUBBER LINING DOWN STREAM TO PEEL WHICH, IN
                              TURN, CREATED A PLUGGING PROBLEM.  EIMCO ENGINEERS ARE PRESENTLY STUDYING
                              THE PROBLEM AND HOPE TO INCORPORATE MODIFICATIONS TO IMPROVE THE PERFOR-
                              MANCE OF THE FILTERS.

 3/78  SYSTEM                                                                 744

 4/78  SYSTEM                                                                 720

        ** PROBLEMS/SOLUTIONS/COMMENTS

                              THE DAMAGED FD FAN WAS REINSTALLED DURING APRIL.  THE AFFECTED MODULE
                              WAS DOWN FROM FEBRUARY 23 THROUGH APRIL 10.

 5/78  SYSTEM                                                                 744

 6/78  SYSTEM                                                                 720

        ** PROBLEMS/SOLUTIONS/COMMENTS

                              COMPLIANCE TESTING TOOK PLACE DURING THE WEEK OF JUNE 5.  THE REPORT
                              SHOULD BE AVAILABLE TO THE UTILITY BY THE END OF JUNE.

                              THE UNIT WAS DOWN WITH DAMPER PROBLEMS (DOWN ON THE 24TH OF JUNE). AP-
                              PARENTLY THE CHAINS THAT PULL THE GUILLOTINE DAMPERS WERE UNDERDESIGNED
                              AND PRONE TO FAILURE.  THE CHAINS ARE CURRENTLY BEING REPLACED.

 7/78  SYSTEM                                                                 744

 8/78  SYSTEM                                                                 744

        ** PROBLEMS/SOLUTIONS/COMMENTS

                              OFFICIAL RESULTS OF THE COMPLIANCE TEST PERFORMED ON JUNE 6 ARE STILL NOT
                              AVAILABLE.  BECAUSE OF INTERMITTENT OPERATION, FGD SYSTEM PERFORMANCE
                              FIGURES ARE NOT YET AVAILABLE.

 9/78  SYSTEM                                                                 720

10/78  SYSTEM                                                                 744
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MINNKOTA POWER COOPERATIVE: MILTON R. YOUNG 2 (CONT.)

PERFORMANCE DATA

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR

** PROBLEMS/SOLUTIONS/COMMENTS

THE THICKENER HAS BEEN A MAJOR PPOBLEM AREA. THE POLYETHYLENE LINER WAS ACCIDENTLY PIERCED WHILE REPAIRS WERE BEING MADE TO SOME OTHER COMPONENTS. THE LINER IS CURRENTLY BEING PATCHED.

THE UTILITY REPORTED THAT OPERATION OF THE BOILER AND FGD SYSTEM CONTINUED ON AN INTERMITTENT BASIS THROUGHOUT THE PERIOD.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
11/78	SYSTEM							720			

** PROBLEMS/SOLUTIONS/COMMENTS

THICKENER PROBLEMS ARE CONTINUING. THE RUBBER LINER HAS BEEN DETATCHING FROM THE THICKENER CONE. THE THICKENER MUST BE DRAINED TO MAKE THE REPAIRS.

FAN PROBLEMS OCCURRED DURING THE PERIOD. THERE IS NO DAMPER BETWEEN THE MODULE AND FAN. UNDER SOME OPERATING CONDITIONS WET GAS CAN BACK INTO THE FAN AREA RESULTING IN CORROSION AND OTHER MOISTURE RELATED PROBLEMS.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
12/78	A	4.6	5.1		4.6						
	B	37.7	28.4		25.7						
	SYSTEM	42.3	33.5	33.8	30.3			744	673	225	54.0

** PROBLEMS/SOLUTIONS/COMMENTS

MINNKOTA POWER COOP REPORTED THE FOLLOWING STATISTICS FOR THE YEAR OF 1978:
TOTAL PERIOD HOURS: 8760
TOTAL BOILER HOURS: 6926
TOTAL A-MODULE HOURS: 1790
TOTAL B-MODULE HOURS: 2110
ANNUAL BOILER CAPACITY FACTOR: 66.7%

FGD SYSTEM PERFORMANCE:

	A-MODULE	B-MODULE	SYSTEM
AVAILABILITY	92.3	28.5	46.1
OPERABILITY	28.0	25.9	52.7
RELIABILITY			53.9
UTILIZATION	22.2	20.4	41.7

THE B-TOWER WAS OUT OF SERVICE DURING DECEMBER DUE TO PLUGGING OF THE THICKENER UNDERFLOW BY RUBBER LINING. THE THICKENER WAS PUMPED OUT AND REPAIRED.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
1/79	A	4.6	5.1		4.6						
	B	37.7	28.4		25.7						
	SYSTEM	42.3	33.5	33.8	30.3			744	673	225	54.0

** PROBLEMS/SOLUTIONS/COMMENTS

SOME WEATHER-RELATED PROBLEMS OCCURRED WITH FGD SYSTEM PIPING FREEZE-UPS.

THE UTILITY REPORTED THAT THE A-TOWER WAS OUT OF SERVICE FOR A PERIOD IN JANUARY DUE TO BROKEN INLET ISOLATION DAMPER CHAINS.

THE A-TOWER WAS OUT OF SERVICE TO REPAIR A BOOSTER FAN SERVO MECHANISM THROUGH JANUARY 28.

THE B-TOWER WAS OUT OF SERVICE FROM DECEMBER 27 THROUGH JANUARY 31 DUE TO A FAN MOTOR FAILURE.

THE UTILITY REPORTED THAT EROSION PROBLEMS IN THE SCRUBBER TOWERS ARE

SEVERE ENOUGH THAT HOLES HAVE BEEN DISCOVERED IN TOWER WALLS.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
2/79	A	19.4	26.5		19.4						
	B	32.1	44.0		32.1						
	SYSTEM	51.5	70.5	70.5	51.5			672	491	346	58.1
3/79	A	19.4	26.5		19.4						
	B	32.1	44.0		32.1						
	SYSTEM	51.5	70.5	70.5	51.5			744	543	383	58.1

** PROBLEMS/SOLUTIONS/COMMENTS

TWO DAYS OF DOWN TIME WERE REQUIRED TO REMOVE LOOSE RUBBER FROM THE THICKENER PIPING DURING THE FEBRUARY-MARCH PERIOD.

A BOOSTER FAN MOTOR FIRE OCCURRED IN THE A-MODULE.

HOLES IN THE B-SIDE ABSORBER TOWER WERE REPAIRED DURING THE PERIOD.

COLD WEATHER INHIBITED SCRUBBER STARTUPS AFTER REPAIRS WERE MADE DURING THE PERIOD.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
4/79	A	3.0	3.2		3.0						
	B	57.1	61.6		57.1						
	SYSTEM	60.1	64.8	65.4	60.1			720	668	432	69.4
5/79	A	3.0	3.2		3.0						
	B	57.1	61.6		57.1						
	SYSTEM	60.1	64.8	65.4	60.1			744	690	448	88.4

** PROBLEMS/SOLUTIONS/COMMENTS

THE A-MODULE IS STILL EXPERIENCING FAN PROBLEMS. DURING APRIL AND MAY THE FAN HAD ALIGNMENT PROBLEMS POSSIBLY RELATED TO THE FAN FOUNDATION.

DURING APRIL AND MAY HOLES WERE REPAIRED IN THE ABSORBER WALLS, VALVE REPAIRS WERE MADE, AND REPAIRS WERE MADE ON A THICKENER DRIVE GEAR.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
6/79	A	17.2	17.2		17.2						
	B	36.3	36.3		36.3						
	SYSTEM	52.8	52.8	52.8	52.8			720	720	300	88.7

** PROBLEMS/SOLUTIONS/COMMENTS

THE A-TOWER WAS DOWN FOR REPAIR TO THE FLAKE LINING.

THE FGD SYSTEM WAS DOWN FOR PART OF THE MONTH FOR REPAIRS AFTER EXCESS SOLIDS ENTERING THE TRAY RECYCLE LOOP OVERLOADED THE CLARIFIER.

AN A-TOWER TRAY RECYCLE DISTRIBUTION HEADER WAS CLEANED DURING JUNE.

THE SYSTEM WAS FORCED OUT OF SERVICE WHEN BOILER PROBLEMS CAUSED AN EXCESSIVE AMOUNT OF HEAVY PARTICLES (SLAG CARRYOVER) TO ENTER THE FGD SYSTEM RESULTING IN THE PLUGGING OF SEVERAL LINES AND STOPPING THE THICKENER RAKE. SLUDGE HAD TO BE DREDGED AND HAULED OUT FROM THE TOP OF THE THICKENER.

THE A-TOWER WAS OUT OF SERVICE DUE TO PROBLEMS WITH THE WATER BALANCE AND THE VACUUM FILTERS AS WELL AS TO UNPLUG THE ABSORBER BLEED LINE. LIME WAS USED FOR SEVERAL DAYS AS MAKE UP CHEMICAL (AS OPPOSED TO PRIMARILY ALKALINE FLYASH) TO EASE THE HIGH SOLIDS PROBLEM.

A-TOWER AGITATOR GEARS WHICH FAILED AS A RESULT OF A CLARIFIER OVERLOAD WERE REPLACED DURING THE PERIOD.

MINNKOTA POWER COOPERATIVE, MILTON R. YOUNG 2 (CONT.)

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
7/79	A	44.5	44.5		44.5						
	B	.0	.0		.0						
	SYSTEM	44.0	44.0	44.0	44.0			744	744	331	86.7

** PROBLEMS/SOLUTIONS/COMMENTS

THE UTILITY HAS REPORTED THAT A TRAY RECYCLE CONTROL VALVE AND AN ABSORBER TRAIN VALVE FAILED DURING JULY.

THE UTILITY REPORTED PROBLEMS WITH PLUGGING IN THE MIST ELIMINATORS, THE THICKENER AND IN THE ABSORBER FEED LINE.

THE UNIT EXPERIENCED A BOOSTER FAN TRIP IN JULY.

PROBLEMS WITH THE VACUUM FILTERS AND THE SEAL WATER PUMP WERE ENCOUNTERED.

THE ABSORBER AGITATOR WAS REPLACED DURING JULY.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
8/79	A	28.7	28.7		28.7						
	B	10.6	10.6		10.6						
	SYSTEM	39.0	39.0	39.0	39.0			744	744	293	92.3

** PROBLEMS/SOLUTIONS/COMMENTS

DURING AUGUST EXCESSIVE VIBRATION AND HIGH BEARING TEMPERATURE IN THE A-SIDE BOOSTER FAN WERE ENCOUNTERED CAUSING SOME DOWN TIME.

THE INABILITY TO ADD ALKALI (FLYASH OR LIME) TO THE SYSTEM CAUSED SOME OPERATIONAL PROBLEMS ON THE A-SIDE SCRUBBER.

DURING AUGUST THE B-SIDE THICKENER RAKE WAS BURIED IN THE SLUDGE. THE SLUDGE HAD TO BE REMOVED BY MINING IT FROM THE TOP.

PLUGGING OF THE FLYASH TANK AND THE LIME SLURRY FEED LINE CAUSED SOME B-SIDE OUTAGE TIME DURING AUGUST.

DUE TO A LACK OF LIME (THE UTILITY SUPPLY WAS EXHAUSTED) THE FGD SYSTEM HAD TO SHUT DOWN.

THE HOLES IN THE SIDES OF THE B-SIDE ABSORBER TOWER HAD TO BE REPAIRED CAUSING SOME OUTAGE TIME IN AUGUST.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
9/79	A	21.4	21.5		21.4						
	B	1.2	1.2		1.2						
	SYSTEM	23.0	23.0	23.0	23.0			720	717	163	96.6

** PROBLEMS/SOLUTIONS/COMMENTS

DURING SEPTEMBER THE A-SIDE WAS DOWN DUE TO HEAVY SOLIDS IN THE THICKENER AND CLARIFIER. HIGH VIBRATIONS WERE EXPERIENCED WITH THE BOOSTER FAN.

THE B-SIDE REMAINED OUT OF SERVICE DUE TO PROBLEMS WITH THE THICKENER AND CLARIFIER.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
10/79	A	.0	.0		.0						
	B	31.3	31.4		31.3						
	SYSTEM	31.3	31.4	31.4	31.3			744	743	233	89.7

** PROBLEMS/SOLUTIONS/COMMENTS

THE UTILITY IS IN THE PROCESS OF CLEANING THE CLARIFIER.

THE CLARIFIER AGITATOR DRIVE GEAR FAILED CAUSING DOWN TIME FOR REPAIR IN

```
------------------------------------------PERFORMANCE DATA-------------------------------------------
PERIOD MODULE AVAILABILITY OPERABILITY RELIABILITY UTILIZATION  % REMOVAL   PER  BOILER  FGD   CAP.
                                                                SO2  PART. HOURS HOURS  HOURS FACTOR
------ ------ ------------ ----------- ----------- ----------- ----- ----- ----- ------ ----- ------
                           OCTOBER.

                           THE BLEED LINE TO THE THICKENER PLUGGED AND NEEDED MAINTENANCE.

                           THE GEAR HOUSING FAILED ON THE THICKENER LIFT MECHANISM CAUSING OUTAGE
                           TIME FOR REPAIR.

11/79  A            .6          .7                      .6
       B          15.4        16.7                    15.4
       SYSTEM     16.0        17.4        17.4        16.0                    720   661   115  80.0

       ** PROBLEMS/SOLUTIONS/COMMENTS

                           AN EXCESS OF SOLIDS CAUSED PLUGGING IN THE THICKENER AND THE CLARIFIER
                           DURING NOVEMBER.

12/79  A          26.6        31.5                    26.6
       B           9.7        11.5                     9.7
       SYSTEM     36.3        43.0        43.0        36.3                    744   628   270  67.2

       ** PROBLEMS/SOLUTIONS/COMMENTS

                           PLUGGING OF THE SEAL WATER SYSTEM RESULTED IN SOME OUTAGE TIME DURING
                           DECEMBER.

                           BOOSTER FAN PROBLEMS RELATED TO EXCESSIVE VIBRATION WERE ENCOUNTERED ON
                           MODULE B IN DECEMBER.

                           A HOLE IN A BLOCKING VALVE RESULTED IN SOME DOWNTIME.

                           THE GEAR HOUSING FAILED ON THE THICKENER LIFT MECHANISM.

 1/80  A           7.1        10.5                     7.1
       B            .0          .0                      .0
       SYSTEM      7.1        10.5        10.5         7.1                    744   504    53  58.5

       ** PROBLEMS/SOLUTIONS/COMMENTS

                           DURING JANUARY A COLD WEATHER CAUSED SOME PIPE LINES AND A BOOSTER
                           FAN ICE UP.

                           A HIGH PERCENTAGE OF COARSE SOLIDS IN THE THICKENER CAUSED SOME OUTAGE
                           TIME.  THE WORM GEAR ON THE THICKENER FAILED ADDING TO THE OUTAGE TIME.

                           CLEANING AND REPAIR OF THE THICKENER WAS COMPLICATED BY SUB-ZERO AMBIENT
                           TEMPERATURES.

 2/80  SYSTEM       .0          .0                      .0                    696   696     0  97.1

       ** PROBLEMS/SOLUTIONS/COMMENTS

                           PROBLEMS RELATED TO THE COLD WEATHER CONTINUED THROUGH FEBRUARY.  ICE
                           ON THE BOOSTER FAN HAD TO BE MELTED BEFORE IT COULD BE OPERATED.

                           SHAFT SLEEVES ON SEVERAL SPRAY RECYCLE PUMPS WERE REPLACED DURING
                           FEBRUARY.

                           THE GEAR REDUCER FAILED ON THE B-SIDE ABSORBER AGITATOR PREVENTING SCRUB-
                           BER OPERATION.

                           THE ISOLATION DAMPER CHAINS BROKE DURING THE MONTH.

 3/80  A          22.6        22.6                    22.6
```

MINNKOTA POWER COOPERATIVE: MILTON R. YOUNG 2 (CONT.)

PERFORMANCE DATA

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
	B	6.2	6.2		6.2						
	SYSTEM	28.9	28.8	28.8	28.8			744	743	214	89.1

** PROBLEMS/SOLUTIONS/COMMENTS

DURING MARCH COLD WEATHER CONTINUED TO BE A PROBLEM.

THE TORQUE SWITCHES ON THE ISOLATION DAMPERS WERE REPLACED. THE DAMPER PROBLEMS CAUSED THE BOOSTER FAN TO TRIP. THE OUTAGE TIME WAS EXTENDED BECAUSE THE UTILITY HAD TO WAIT FOR THE SWITCHES TO BE DELIVERED.

AN EXCESSIVE AMOUNT OF COARSE PARTICLES IN THE THICKENER CONTINUED TO BE A PROBLEM. PLUGGED BLEED LINES FROM THE ABSORBER TO THE THICKENER WERE ALSO ENCOUNTERED.

THE A-SIDE ABSORBER AGITATOR ANCHOR BOLTS SHEARED DURING MARCH CAUSING MODULE DOWN TIME.

THE SHAFT SLEEVES ON THE SPRAY RECYCLE PUMPS WOULD NOT HOLD THE PUMP GLAND PACKING. THE SHAFT SLEEVES ARE CURRENTLY BEING REPLACED.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
4/80	A	100.0	.0		.0						
	B	.0	.0	.0	.0						
	SYSTEM	100.0	.0	.0	.0			720	154	0	

** PROBLEMS/SOLUTIONS/COMMENTS

THE UNIT WAS DOWN FOR APPROXIMATELY 3 WEEKS FOR THE ANNUAL UNIT OUTAGE DURING APRIL.

PLUGGED BLEED LINES AND THE REPLACEMENT OF THE SHAFT SLEEVES ON THE RECYCLE PUMPS CAUSED THE FGD SYSTEM TO REMAIN OFF LINE DURING THE TIME THE BOILER OPERATED.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
5/80	A	.0	.0		.0						
	B	47.2	48.4	50.6	45.6						
	SYSTEM	47.2	48.4	50.6	45.6			744	700	339	

** PROBLEMS/SOLUTIONS/COMMENTS

MODULE B WAS OPERATED DURING MAY WHILE REPAIR WORK WAS BEING DONE ON MODULE A.

THE REPAIRS ON MODULE A INCLUDED WORK ON THE SPRAY RECYCLE NOZZLE PIPING, AND THE RECYCLE HEADER.

THE VALVES ON BOTH THE SPRAY RECYCLE PUMP AND THE DISCHARGE SPRAY CYCLE PUMP WERE REPAIRED.

THE ABSORBER LINING HAS STARTED TO WEAR AND IS NOW BEING REPAIRED.

HIGH SOLIDS RESULTED IN THICKNER LINE PLUGGING. HIGH SOLIDS ALSO CAUSED PROBLEMS WITH THE RAKE AND CONE. BOTH THE THICKNER AND THE CLARIFIER HAD TO BE DRAINED AND CLEANED.

THE ABSORBER AGITATOR TUNNEL WAS ALSO CLEANED DURING THE MONTH.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
6/80	A	.0	.0		.0						
	B	41.8	40.4	41.4	39.3						
	SYSTEM	41.8	40.4	41.4	39.3			720	701	283	

PERFORMANCE DATA

** PROBLEMS/SOLUTIONS/COMMENTS

MODULE B CONTINUED TO OPERATE THROUGH JUNE.

PROBLEMS WITH THE THICKNER CONTINUED THROUGH THE MONTH. HIGH SOLIDS CAUSED PROBLEMS WITH THE RAKE MECHANISM AND THE LIMIT SWITCH.

TROUBLE WAS ENCOUNTERED DURING JUNE WITH THE VACUUM FILTER.

THE REPAIR WORK CONTINUED ON THE ABSORBER FLAKE LININGS.

MODULE A REPAIR WORK CONTINUED DURING JUNE.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	% REMOVAL PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
7/80	A	.0	.0		.0						
	B	65.3	64.5	65.8	52.0						
	SYSTEM	65.3	64.5	65.8	52.0			744	600	387	60.0

** PROBLEMS/SOLUTIONS/COMMENTS

PROBLEMS WITH THE RAKE MECHANISM AND UNDERFLOW PUMPS IN THE THICKENER CONTINUED IN JULY. HIGH SOLIDS IN THE THICKENER ARE CAUSED WHEN FLY ASH IS ADDED TO THE LIME IN THE ABSORBER TOWER. THE ABSORBER REAGENT IS CHANGED TO STRAIGHT LIME WHEN THIS OCCURS.

PROBLEMS WERE ENCOUNTERED WITH THE TWO VACUUM FILTER PUMPS. ONE WAS BEING REBUILT WHILE THE OTHER FUNCTIONED POORLY.

REPAIRS WERE MADE TO THE LEAK IN THE ABSORBER TOWER.

PROBLEMS WERE REPORTED WITH THE MOTOR AND DISCHARGE VALVE ON THE TRAY RECYCLE PUMPS.

THE FGD SYSTEM WAS NOT PLACED IN SERVICE WHEN THE BOILER WAS RUN AT REDUCED LOAD DURING THE MONTH.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	% REMOVAL PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
8/80	A	90.7	54.3	98.8	53.9						
	B	56.9	44.2	99.4	44.0						
	SYSTEM	99.2	98.6	99.2	98.0			744	739	729	92.8

** PROBLEMS/SOLUTIONS/COMMENTS

BOTH MODULES WERE OPERATED DURING AUGUST.

DURING THE MONTH, MAINTENANCE WORK WAS DONE ON THE TEFLON PACKING OF THE SPRAY RECYCLE PUMPS. THE VACUUM FILTER DRUM, SPRAY NOZZLES, THE ABSORBER AGITATOR, THE CLARIFIER CONE, AND THE THICKNER RAKE MECHANISM.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	% REMOVAL PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
9/80	A	70.1	72.6	100.0	66.9						
	B	66.7	25.1	100.0	23.2						
	SYSTEM	100.0	97.9	100.0	90.3			720	664	650	78.5

** PROBLEMS/SOLUTIONS/COMMENTS

THE FGD SYSTEM WAS AVAILABLE DURING ALL OF SEPTEMBER.

BOTH MODULES WERE OPERATED DURING THE MONTH.

PERIOD	MODULE	AVAILABILITY	OPERABILITY	RELIABILITY	UTILIZATION	% REMOVAL SO2	% REMOVAL PART.	PER HOURS	BOILER HOURS	FGD HOURS	CAP. FACTOR
10/80	A	90.4	85.4	87.1	76.2						
	B	17.7	.0		.0						
	SYSTEM	100.0	85.4	87.1	76.2			744	664	744	75.7

MINNKOTA POWER COOPERATIVE: MILTON R. YOUNG 2 (CONT.)

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-------------------------------------------PERFORMANCE DATA---------------------------------------------
PERIOD MODULE AVAILABILITY OPERABILITY RELIABILITY UTILIZATION  % REMOVAL   PER  BOILER  FGD   CAP.
                                                                SO2  PART. HOURS HOURS  HOURS FACTOR
------ ------ ------------ ----------- ----------- ----------- ----- ----- ----- ------ ----- ------

        ** PROBLEMS/SOLUTIONS/COMMENTS

                           DURING OCTOBER AVAILABILITY FOR MODULE B WAS LOW DUE TO LEAKS IN THE TOWER.

11/80  A          42.2        40.4        100.0       38.7
       B          98.6        54.0         96.4       50.1
       SYSTEM    100.0        94.5         99.1       90.6                      720   690    720  88.6

        ** PROBLEMS/SOLUTIONS/COMMENTS

                           AVAILABILITY WAS LOW FOR MODULE A DUE TO LEAKS IN THE TOWER DURING THE
                           MONTH OF NOVEMBER.

12/80  A          41.5        33.2         54.5       40.0
       B          30.0        29.5         88.6       28.4
       SYSTEM     71.5        62.8         66.7       60.5                      744   716    450  92.4

        ** PROBLEMS/SOLUTIONS/COMMENTS

                           DURING DECEMBER AVAILABILITY WAS LOW DUE TO DOWN TIME NECESSARY TO CONVERT
                           FROM A THICKENER TO SLUDGE PONDS AND PROBLEMS WITH THE OVERFLOW LEVEL
                           CONTROL OF THE ABSORBER.

                           ISOLATION DAMPER PROBLEMS DURING THE MONTH DELAYED THE STARTUP OF THE
                           FGD SYSTEM.
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APPENDIX B. SITE DEVELOPMENT AND GEOHYDROLOGY

GEOHYDROLOGIC AND HYDROGEOCHEMICAL DATA, CENTER AREA

B.1. Introduction

The Center area is located on an upland divide bounded on the north and northeast by the Square Butte Creek Valley and on the south by the Hagel Creek Valley. Figure B-1 shows the locations of piezometer nests in the area adjacent to the detailed study site. (Figure B-2).

The shallow bedrock hydrostratigraphic units within the Center area consist of sand, silty sand, and lignite aquifers separated by silty and clayey materials (Figure B-3). Much of the area is overlain by a veneer of glacial till. Glaciofluvial sand and gravel aquifers are present in the Square Bute Creek Valley. The shallow stratigraphic units of major interest hydrologically in the unmined area include two lignites; the Kinneman Creek bed and the Hagel bed, and a clayey sand unit which lies approximately 15 m below the Hagel bed (Figure B-3). Much of the interval between the lignites (Kinneman Creek interval) consists of sandy materials as does part of the body of materials overlying the Kinneman Creek bed. The hydrologic units of major interest in the detailed study site include the spoil materials and unmined materials within 18 m of the base of the spoils. Table B-1 lists all piezometers in the detailed study site (I-46) installed during this project, and those in adjacent unmined areas (360-379) installed prior to this project. The depth and stratigraphic position of each piezometer is indicated. Tables B-2 and B-3 list the hydraulic head values for piezometers in the unmined area and the detailed study site, respectively.

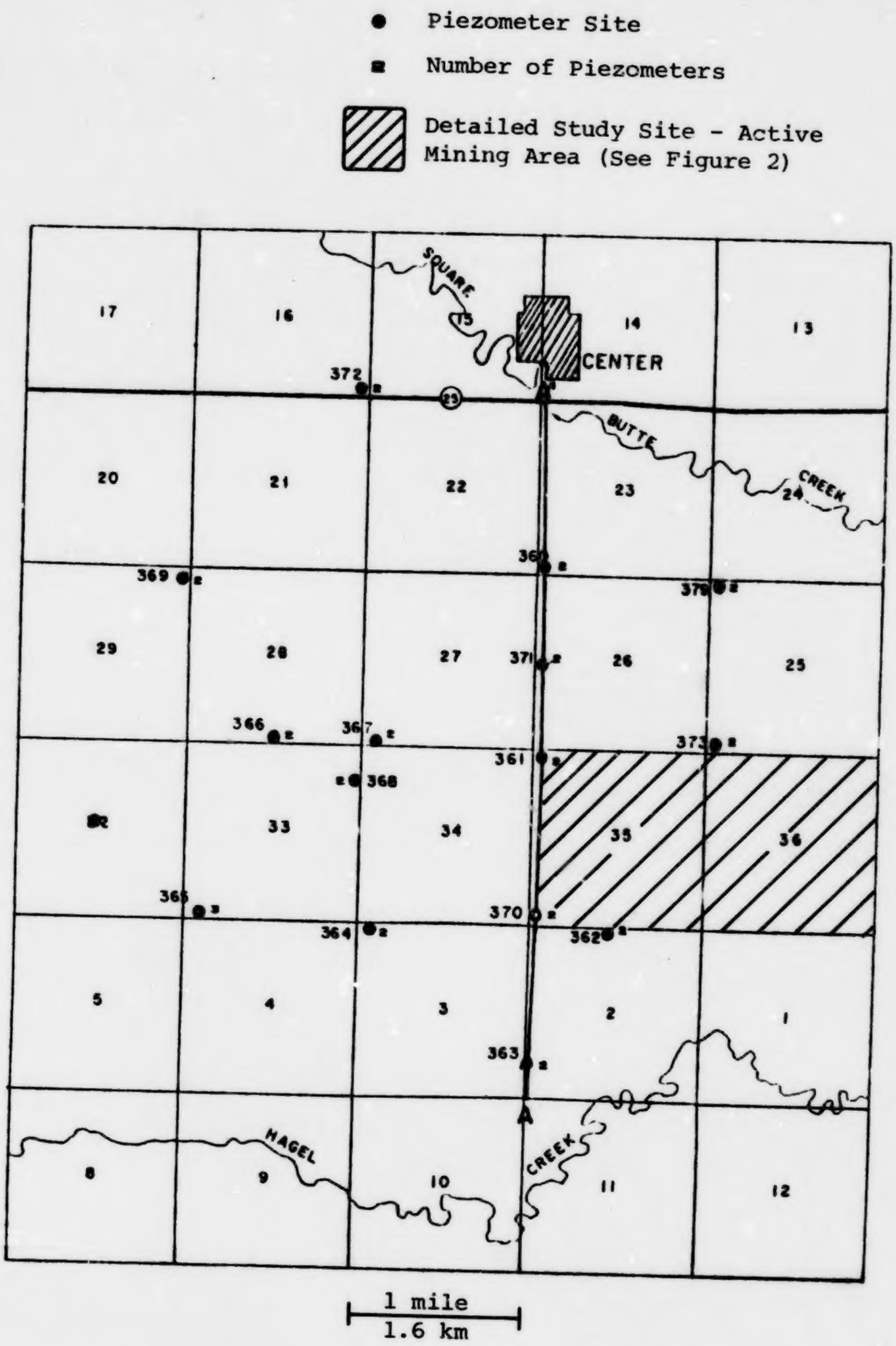
● Piezometer Site
■ Number of Piezometers
▨ Detailed Study Site - Active Mining Area (See Figure 2)
SQUARE
BUTTE
CREEK
CENTER
HAGEL
CREEK
A
A¹
23
17
16
15
14
13
20
21
22
23
24
29
28
27
26
25
32
33
34
35
36
5
4
3
2
1
8
9
10
11
12
372
369
360
371
374
366
367
368
361
373
365
370
364
362
363
1 mile
1.6 km

Figure B-1. Location of Piezometers and Cross Section A-A¹ in the Center Area and Detailed Study Site in the Active Mining Area.

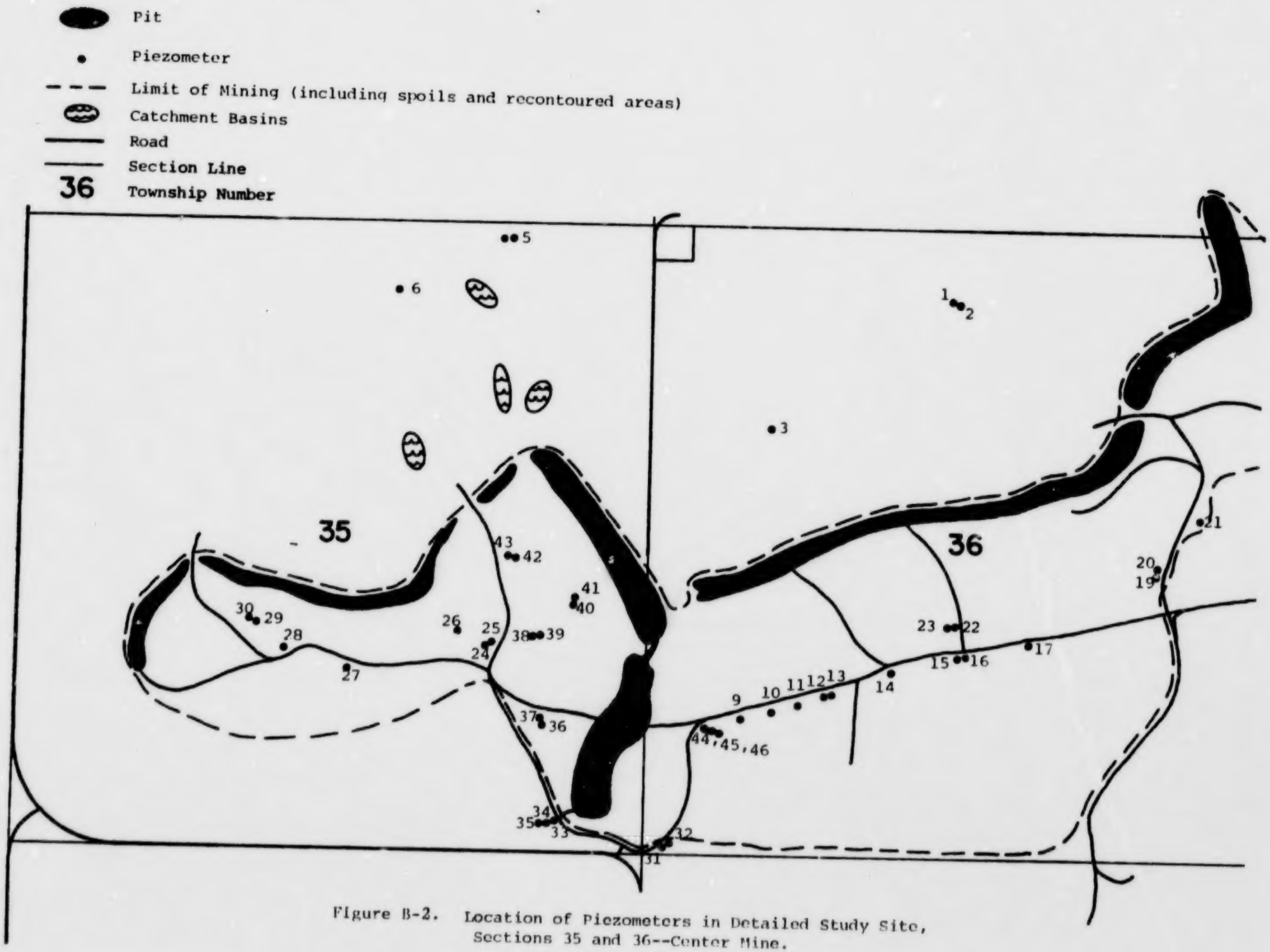
Pit
Piezometer
Limit of Mining (including spoils and recontoured areas)
Catchment Basins
Road
Section Line
36 Township Number
35
36
1
2
3
5
6
9
10
11
12
13
14
15
16
17
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44,45,46

Figure B-2. Location of Piezometers in Detailed Study Site, Sections 35 and 36--Center Mine.

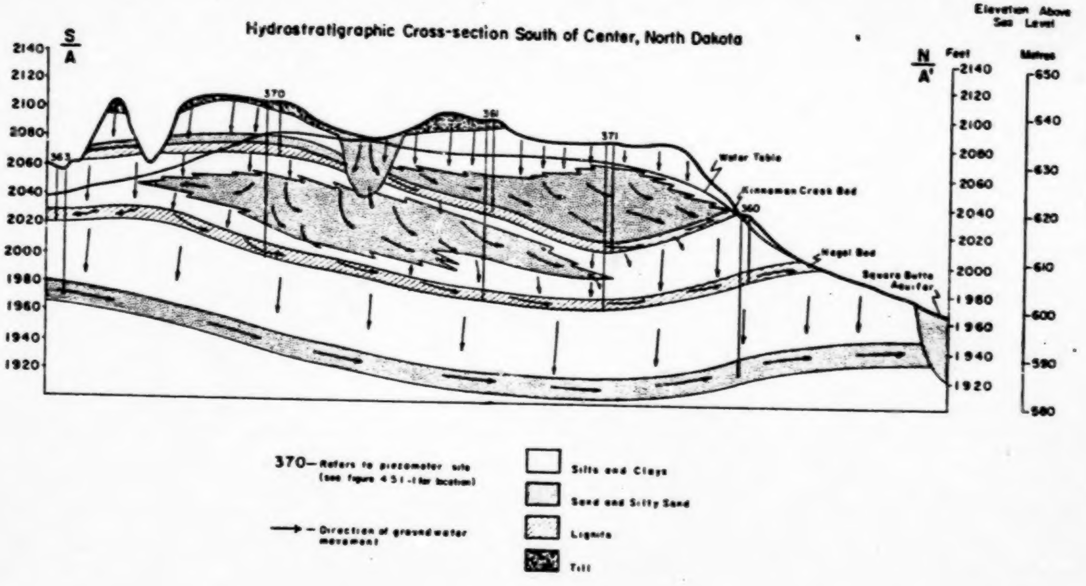
Hydrostratigraphic Cross-section South of Center, North Dakota
S
A
N
A'
Elevation Above Sea Level
Feet
Metres
2140
2120
2100
2080
2060
2040
2020
2000
1980
1960
1940
1920
650
640
630
620
610
600
590
580
363
370
361
371
360
Water Table
Kinneman Creek Bed
Hagel Bed
Square Butte Aquifer
370— Refers to piezometer site (see figure 4.5.1-1 for location)
→ – Direction of groundwater movement
Silts and Clays
Sand and Silty Sand
Lignite
Till

Figure B-3. Hydrostratigraphic cross section of the Center area. See Figure 1 for location of cross section

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Table B-1. Depth and stratigraphic position of piezometers in the Center area.

Wells in detailed study site; see figure 2 for locations.

Well No.	Depth (m)	Stratigraphic Unit
1	40.23	Hagel bed
2	55.47	~12m below Hagel bed
3	43.28	Hagel bed
5	35.66	Hagel bed
6	40.84	Hagel bed
9	15.24	Spoils
10	15.85	Spoils
11	15.85	Spoils
12	28.35	~15m below spoils
13	16.15	Spoils
14	14.94	Spoils
15	27.43	~12m below spoils
16	15.24	Spoils
17	20.73	Spoils
19	28.35	~12m below spoils
20	16.15	Spoils
21	17.37	Spoils
22	29.57	~12m below spoils
23	17.37	Spoils
24	30.48	~12m below spoils
25	18.29	Spoils
26	20.42	Spoils
27	16.76	Spoils
28	21.95	Spoils
29	36.58	~15m below Hagel bed
30	24.38	Hagel bed
31	30.48	~15m below Hagel bed
32	16.00	Hagel bed
33	35.05	~18m below Hagel bed
34	22.86	~5m below Hagel bed
35	16.76	Hagel bed
36	17.98	~3m below spoils
37	9.75	Spoils
38	23.16	~9m below spoils
39	17.68	Spoils
40	24.38	~5m below spoils
41	17.07	Spoils
42	22.86	~3m below spoils
43	19.81	Spoils
44	24.38	~8m below spoils
45	16.15	Hagel bed
46	13.72	Spoils

Wells in proposed mining area; see figure 1 for locations.

Well No.	Depth (m)	Stratigraphic Unit
360 A	33.0	~15m below Hagel bed
360 B	14.0	Hagel bed
361	36.9	Hagel bed
361 A	19.7	Kinneman Creek bed
362	25.0	~15m below Hagel bed
362 A	9.7	Hagel bed
363	25.0	~13m below Hagel bed
363 A	12.4	Hagel bed
364	24.2	Hagel bed
364 A	10.1	Kinneman Creek bed
365	43.1	~15m below Hagel bed
365 A	27.9	Hagel bed
365 B	13.9	Kinneman Creek bed
366	35.9	Hagel bed
366 A	20.6	Kinneman Creek bed
367	55.4	Hagel bed
367 A	40.3	Kinneman Creek bed
368	34.9	Hagel bed
368 A	22.6	Kinneman Creek bed
369	39.4	Hagel bed
369 A	33.0	Kinneman Creek bed
370	31.3	Hagel bed
370 A	11.8	Kinneman Creek bed
371	34.2	Hagel bed
371 A	21.2	Kinneman Creek bed
372	14.9	Hagel bed
372 A	9.8	Kinneman Creek bed
373 A	25.6	Hagel bed
373 B	13.1	Kinneman Creek bed
379	27.6	Hagel bed
379 A	8.3	Kinneman Creek bed

Table B-2. Hydraulic head values for piezometers in area adjacent to detailed study site.

142-084-23 CCC
Well # 360 A
Depth: 34.1m
Ground Elev: 620.3m
Well Head Elev: 621.4m

Date	Water Level
5-14-76	588.83
6- 2-76	599.94
7-12-76	599.94
7-26-76	599.92
8- 9-76	599.90
8-23-76	599.90
9- 9-76	599.88
9-20-76	599.88
10- 4-76	599.89
10-18-76	599.87
11- 1-76	599.88
11-24-76	599.87
12-14-76	599.89
1- 4-77	599.91
1-27-77	599.91
2-15-77	599.89
3- 3-77	599.90
4-19-77	599.88
4-27-77	599.89
7-19-77	599.55
9- 6-77	599.84
10-10-77	599.94
1-26-78	600.00
2-28-78	599.97
3-27-78	599.95
4-20-78	599.90
5-23-78	599.90
6-14-78	599.89
7-21-78	598.77
8-24-78	599.45
9-22-78	599.84
10-19-78	599.80
12-12-78	599.91
3-21-79	Destroyed

142-084-22 DDD
Well # 360 B
Depth: 15.2m
Ground Elev: 620.3m
Well Head Elev: 620.36m

Date	Water Level
5-14-76	608.01
6- 2-76	608.12
7-12-76	608.09
7-26-76	608.07
8- 9-76	608.07
8-23-76	608.06
9- 9-76	608.04
9-20-76	608.04
10- 4-76	608.04
10-18-76	608.04
11- 1-76	608.05
11-24-76	608.05
12-14-76	608.04
1- 4-77	608.05
1-27-77	608.03
2-15-77	608.04
3- 3-77	608.05
4-19-77	608.06
4-27-77	608.03
7-19-77	607.68
9- 6-77	607.98
10-10-77	608.05
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	608.14
4-20-78	608.00
5-23-78	607.98
6-14-78	607.99
7-21-78	608.04
8-24-78	607.56
9-22-78	607.63
10-19-78	607.68
12-12-78	Destroyed

142-084-35 BBB
Well # 361
Depth: 38.0m
Ground Elev: 638.7m
Well Head Elev: 639.8m

Date	Water Level
5-14-76	607.04
6- 2-76	607.29
7-12-76	607.89
7-26-76	607.68
8- 9-76	607.59
8-23-76	607.47
9-20-76	607.35
10- 4-76	607.32
10-18-76	607.25
11- 1-76	607.22
11-24-76	607.19
12-14-76	607.16
1- 4-77	607.10
1-27-77	607.10
4-19-77	607.50
4-27-77	607.53
7-19-77	607.01
9- 6-77	607.16
10-10-77	dry
12-21-77	inaccessible
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	607.56
4-20-78	Destroyed

Table B-2. (continued)

142-084-35 BBB
Well # 361 A
Depth: 20.1m
Ground Elev: 639.1m
Well Head Elev: 639.5m

Date	Water Level
5-14-76	623.87
6- 2-76	624.14
7-12-76	624.20
7-26-76	624.16
8- 9-76	624.23
8-23-76	624.21
9- 9-76	624.18
9-20-76	623.88
10- 4-76	623.97
10-18-76	623.97
11- 1-76	624.04
11-24-76	624.06
12-14-76	624.07
1- 4-77	624.06
1-27-77	624.14
2-15-77	624.19
3- 3-77	623.95
4-19-77	623.95
4-27-77	623.87
7-19-77	623.47
9- 6-77	623.74
10-10-77	623.40
12-21-77	623.01
1-26-78	622.89
2-28-78	622.87
3-27-78	622.22
4-20-78	622.44
5-23-78	622.66
6-14-78	622.69
7-21-78	622.23
8-24-78	622.61
9-22-78	622.55
10-19-78	622.50
12-12-78	622.39
3-21-79	622.28
5- 2-79	622.75
6-10-79	622.83
7- 5-79	622.81
8- 1-79	622.83

141-084-02 BAA
Well # 362
Depth: 26.2m
Ground Elev: 619.9m
Well Head Elev: 621.1m

Date	Water Level
5-14-76	609.62
6- 2-76	607.90
7-12-76	608.15
7-26-76	608.12
8- 9-76	608.10
8-23-76	608.08
9- 9-76	608.06
9-20-76	608.05
10- 4-76	608.06
10-18-76	608.04
11- 1-76	608.03
11-24-76	608.05
12-14-76	608.06
1- 4-77	608.07
1-27-77	608.09
2-15-77	608.08
3- 3-77	608.08
4-19-77	608.10
4-27-77	608.10
7-19-77	605.80
9- 6-77	607.84
10-10-77	608.00
12-21-77	608.18
1-26-78	608.17
2-28-78	608.18
3-27-78	607.98
4-20-78	608.18
5-23-78	608.25
6-14-78	608.24
7-21-78	607.82
8-24-78	606.85
9-22-78	606.01
10-19-78	607.82
12-12-78	607.55
5- 2-79	607.90
6-10-79	607.83
7- 5-79	607.97
8- 1-79	608.18

141-084-02 ABB
Well # 362 A
Depth: 10.7m
Ground Elev: 620.0m
Well Head Elev: 621.0m

Date	Water Level
5-14-76	612.45
6- 2-76	612.47
7-12-76	612.53
7-26-76	612.43
8- 9-76	612.47
8-23-76	612.52
9- 9-76	612.42
9-20-76	605.38
10- 4-76	612.30
10-18-76	612.26
11- 1-76	612.22
11-24-76	612.19
12-14-76	612.14
1- 4-77	612.08
1-27-77	612.07
2-15-77	612.05
3- 3-77	612.06
4-19-77	612.18
4-27-77	612.18
7-19-77	611.83
9- 6-77	611.91
10-10-77	612.47
12-21-77	611.80
1-26-78	612.27
2-28-78	612.18
3-27-78	613.02
4-20-78	613.47
5-23-78	613.66
6-14-78	613.41
7-21-78	612.67
8-24-78	612.82
9-22-78	612.67
10-19-78	612.55
12-12-78	612.40
3-21-79	612.40
5- 2-79	613.44
5-10-79	613.31
7- 5-79	613.27
8- 1-79	613.12

Table B-2. (continued)

141-084-03 DDA
Well # 363
Depth: 26.1m
Ground Elev: 626.6m
Well Head Elev: 627.7m

Date	Water Level
5-14-76	612.37
6- 2-76	610.66
7-12-76	610.72
7-26-76	610.63
8- 9-76	610.60
8-23-76	610.59
9- 9-76	610.56
9-20-76	610.56
10- 4-76	610.56
10-18-76	610.54
11- 1-76	610.55
11-24-76	610.53
12-14-76	610.55
1- 4-77	610.55
1-27-77	610.58
2-15-77	610.58
3- 3-77	610.57
4-19-77	610.57
4-27-77	610.56
7-19-77	610.12
9- 6-77	610.49
10-10-77	610.61
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	inaccessible
4-20-78	610.64
5-23-78	610.70
6-14-78	610.67
7-21-78	610.21
8-24-78	610.54
9-22-78	610.58
10-19-78	610.56
12-12-78	610.62
3-21-79	610.77
5- 2-79	610.74
6-10-79	610.77
7- 5-79	610.79
8- 1-79	610.78

141-084-03 DDA
Well # 363 A
Depth: 13.5m
Ground Elev: 626.8m
Well Head Elev: 627.9m

Date	Water Level
5-14-76	615.40
6- 2-76	615.39
7-12-76	615.53
7-26-76	615.56
8- 9-76	615.55
8-23-76	615.55
9- 9-76	615.55
9-20-76	615.54
10- 4-76	615.54
10-18-78	615.54
11- 1-76	615.55
11-24-76	615.54
12-14-76	615.54
1- 4-77	615.53
1-27-77	615.53
2-15-77	615.52
3- 3-77	615.51
4-19-77	615.52
4-27-77	615.53
7-19-77	615.13
9- 6-77	615.52
10-10-77	615.51
1-26-78	615.46
2-28-78	615.31
3-27-78	inaccessible
4-20-78	615.59
5-23-78	615.59
6-14-78	615.53
7-21-78	615.12
8-24-78	615.46
9-22-78	615.40
10-19-78	615.37
12-12-78	615.19
3-21-79	615.12
5- 2-79	615.49
6-10-79	615.39
7- 5-79	615.38
8- 1-79	615.54

141-084-03 BBB
Well # 364
Depth: 25.2m
Ground Elev: 646.0m
Well Head Elev: 647.0m

Date	Water Level
5-14-76	623.53
6- 2-76	623.26
7-12-76	623.23
7-26-76	623.13
8- 9-76	623.06
8-23-76	622.99
9- 9-76	622.87
9-20-76	622.81
10- 4-76	622.74
10-18-76	622.63
11- 1-76	622.65
11-24-76	622.59
12-14-76	622.56
1- 4-77	622.58
1-27-77	inaccessible
2-15-77	inaccessible
4-19-77	dry
4-27-77	622.53
7-19-77	dry
9- 6-77	dry
10-10-77	622.68
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	inaccessible
4-20-78	622.77
5-23-78	622.84
6-14-78	622.87
7-21-78	622.30
8-24-78	622.50
9-22-78	622.64
10-19-78	622.66
12-12-78	inaccessible
5- 2-79	622.79
6-10-79	622.83
7- 5-79	622.86
8- 1-79	622.86

Table B-2. (continued)

141-084-03 BBB
Well # 364 A
Depth: 12.0m
Ground Elev: 644.0m
Well Head Elev: 647.5m

Date	Water Level
5-14-76	635.76
6- 2-76	635.58
7-12-76	635.92
7-26-76	635.83
8- 9-76	635.88
8-23-76	635.87
9- 9-76	635.85
9-20-76	dry
10- 4-76	dry
10-18-76	dry
11- 1-76	dry
11-24-76	dry
12-14-76	635.81
1- 4-77	dry
1-27-77	inaccessible
2-15-77	inaccessible
4-19-77	635.85
4-27-77	635.86
7-19-77	dry
9- 6-77	dry
10-10-77	dry
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	inaccessible
4-20-78	635.92
5-23-78	635.92
6-14-78	635.87
7-21-78	638.22
8-24-78	635.82
9-22-78	635.82
10-19-78	635.78
12-12-78	inaccessible
5- 2-79	635.88
6-10-79	dry (635.68)
7- 5-79	635.87
8- 1-79	635.86

142-084-33 CCC
Well # 365
Depth: 44.4m
Ground Elev: 645.1m
Well Head Elev: 646.4m

Date	Water Level
5-14-76	615.60
6- 2-76	613.66
7-12-76	610.53
7-26-76	609.70
8- 9-76	608.93
8-23-76	608.25
9- 9-76	607.52
9-20-76	607.11
10- 4-76	606.63
10-18-76	606.20
11- 1-76	605.82
11-24-76	605.28
12-14-76	inaccessible
1- 4-77	inaccessible
1-27-77	inaccessible
2-15-77	inaccessible
4-19-77	inaccessible
4-27-77	603.56
7-19-77	603.27
9- 6-77	603.54
10-10-77	603.53
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	inaccessible
4-20-78	603.08
5-23-78	603.08
6-14-78	603.05
7-21-78	602.99
8-24-78	602.98
9-22-78	602.95
10-19-78	602.90
12-12-78	inaccessible
5- 2-79	602.56
6-10-79	602.51
7- 5-79	602.53
8- 1-79	602.52

142-084-33 CCC
Well # 365 A
Depth: 28.9m
Ground Elev: 645.2m
Well Head Elev: 646.2m

Date	Water Level
5-14-76	622.40
6- 2-76	622.58
7-12-76	622.70
7-26-76	622.64
8- 9-76	622.65
8-23-76	622.68
9- 9-76	622.46
9-20-76	622.48
10- 4-76	618.45
10-18-76	622.47
11- 1-76	622.40
11-24-76	622.36
12-14-76	inaccessible
1- 4-77	inaccessible
1-27-77	inaccessible
2-15-77	inaccessible
4-19-77	inaccessible
4-27-77	622.25
7-19-77	621.79
9- 6-77	621.97
10-10-77	621.95
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	inaccessible
4-20-78	622.23
5-23-78	622.64
6-14-78	622.68
7-21-78	622.02
8-24-78	622.50
9-22-78	622.44
10-19-78	622.36
12-12-78	inaccessible
5- 2-79	623.19
6-10-79	622.56
7- 5-79	623.60
8- 1-79	622.68

Table B-2. (continued)

142-084-33 CCC
Well # 365 B
Depth: 14.8m
Ground Elev: 645.4m
Well Head Elev: 646.3m

Date	Water Level
5-14-76	631.76
6- 2-76	631.88
7-12-76	dry
7-26-76	dry
8- 9-76	dry
8-23-76	dry
9- 9-76	dry
9-20-76	dry
10- 4-76	dry
10-18-76	dry
11- 1-76	dry
11-24-76	dry
12-14-76	inaccessible
1- 4-77	inaccessible
1-27-77	inaccessible
2-15-77	inaccessible
4-19-77	inaccessible
4-27-77	plugged
7-19-77	dry
9- 6-77	dry
10-10-77	dry
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	inaccessible
4-20-78	dry
5-23-78	dry
6-14-78	dry
7-21-78	dry
8-24-78	dry (631.73)
9-22-78	dry (631.73)
10-19-78	dry (631.76)
12-12-78	inaccessible
5- 2-79	dry (631.76)
6-10-79	dry (631.75)
7- 5-79	dry (631.75)
8- 1-79	dry (631.74)

142-084-28 CDD
Well # 366
Depth: 36.7m
Ground Elev: 645.6m
Well Head Elev: 646.4m

Date	Water Level
5-14-76	613.73
6- 2-76	613.73
7-12-76	613.63
7-26-76	613.60
8- 9-76	613.59
8-23-76	613.57
9- 9-76	613.54
9-20-76	613.53
10- 4-76	613.51
11- 1-76	613.47
11-24-76	613.45
12-14-76	613.45
1- 4-77	inaccessible
1-27-77	inaccessible
2-15-77	inaccessible
4-19-77	inaccessible
4-27-77	613.33
7-19-77	611.35
9- 6-77	611.59
10-10-77	611.59
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	inaccessible
4-20-78	inaccessible
5-23-78	inaccessible
6-14-78	611.72
7-21-78	610.60
8-24-78	611.61
9-22-78	611.59
10-19-78	611.52
12-12-78	inaccessible
5- 2-79	inaccessible
6-10-79	611.56
7- 5-79	611.54
8- 1-79	611.52

142-084-28 DCC
Well # 366A
Depth: 21.7m
Ground Elev: 645.5m
Well Head Elev: 646.6m

Date	Water Level
5-14-76	628.16
6- 2-76	628.13
7-12-76	627.92
7-26-76	627.79
8- 9-76	627.85
8-23-76	627.74
9- 9-76	627.60
9-20-76	627.67
10- 4-76	627.67
10-18-76	627.60
11- 1-76	627.71
11-24-76	627.71
12-14-76	627.65
1- 4-77	inaccessible
1-27-77	inaccessible
[illegible]-15-77	inaccessible
4-19-77	inaccessible
4-27-77	627.62
7-19-77	627.21
9- 6-77	627.43
10-10-77	627.39
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	inaccessible
4-20-78	inaccessible
5-23-78	inaccessible
6-14-78	628.76
7-21-78	627.58
8-24-78	628.39
9-22-78	628.05
10-19-78	627.92
12-12-78	inaccessible
Jan-May 79	inaccessible
6-10-79	628.65
7- 5-79	628.64
8- 1-79	628.59

Table B-2. (continued)

142-084-27 CCC
Well # 367
Depth: 56.5m
Ground Elev: 650.8m
Well Head Elev: 651.9m

Date	Water Level
5-14-76	612.99
6- 2-76	612.70
7-12-76	612.46
7-26-76	612.46
8- 9-76	612.42
8-23-76	612.36
9- 9-76	612.28
9-20-76	612.23
10- 4-76	612.16
10-18-76	612.07
11- 1-76	612.00
11-24-76	611.86
12-14-76	611.75
1- 4-77	611.86
1-27-77	inaccessible
2-15-77	611.47
3- 3-77	611.43
4-19-77	611.48
4-27-77	611.39
7-19-77	609.59
9- 6-77	609.66
10-10-77	609.62
1-26-78	609.53
2-28-78	609.59
3-27-78	609.67
4-20-78	610.00
5-23-78	610.46
6-14-78	610.50
7-21-78	609.45
8-24-78	610.19
9-22-78	610.53
10-19-78	610.46
12-12-78	610.28
5- 2-79	610.45
6-10-79	610.69
7- 5-79	610.73
8- 1-79	610.84

142-084-27 CCC
Well # 367 A
Depth: 42.0m
Ground Elev: 650.8m
Well Head Elev: 652.5m

Date	Water Level
5-14-76	625.32
6- 2-76	625.46
7-12-76	625.53
7-26-76	625.49
8- 9-76	625.53
8-23-76	625.48
9- 9-76	625.39
9-20-76	625.41
10- 4-76	625.41
10-18-76	625.37
11- 1-76	625.40
11-24-76	625.40
12-14-76	625.38
1- 4-77	625.33
1-27-77	inaccessible
2-15-77	625.24
3- 3-77	625.30
4-19-77	625.32
4-27-77	625.33
7-19-77	625.15
9- 6-77	625.32
10-10-77	625.36
1-26-78	625.38
2-28-78	625.36
3-27-78	625.45
4-20-78	625.56
5-23-78	625.75
6-14-78	625.78
7-21-78	625.35
8-24-78	625.75
9-22-78	625.69
10-19-78	625.65
12-12-78	625.62
5- 2-79	625.17
6-10-79	625.32
7- 5-79	625.34
8- 1-79	625.40

142-084-33 ADA
Well # 368
Depth: 35.3m
Ground Elev: 639.8m
Well Head Elev: 640.2m

Date	Water Level
5-14-76	610.53
6- 2-76	610.73
7-12-76	611.12
7-26-76	611.12
8- 9-76	611.25
8-23-76	611.26
9- 9-76	611.17
9-20-76	611.23
10- 4-76	611.12
11- 1-76	611.09
11-24-76	610.99
12-14-76	610.83
1- 4-77	610.69
1-27-77	inaccessible
2-15-77	610.53
4-19-77	inaccessible
4-27-77	610.62
7-19-77	610.42
9- 6-77	610.53
10-10-77	610.40
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	inaccessible
4-20-78	608.51
5-23-78	611.25
6-14-78	611.38
7-21-78	610.37
8-24-78	611.51
9-22-78	611.50
10-19-78	611.43
12-12-78	inaccessible
5- 2-79	611.07
6-10-79	611.37
7- 5-79	611.46
8- 1-79	611.64

Table B-2. (continued)

142-084-33 ADA
Well # 368 A
Depth: 23.75m
Ground Elev: 639.5m
Well Head Elev: 640.7m

Date	Water Level
5-14-76	629.23
6- 2-76	629.33
7-12-76	629.45
7-26-76	629.42
8- 9-76	629.42
8-23-76	629.42
9- 9-76	629.27
9-20-76	629.25
10- 4-76	629.21
11- 1-76	629.14
11-24-76	629.09
12-14-76	629.46
1- 4-77	629.03
1-27-77	inaccessible
2-15-77	628.92
4-19-77	inaccessible
4-27-77	628.93
7-19-77	626,67
9- 6-77	626.85
10-10-77	626.88
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	inaccessible
4-20-78	627.19
5-23-78	627.47
6-14-78	627.51
7-21-78	627.08
8-24-78	627.42
9-22-78	627.33
10-19-78	627.27
12-12-78	inaccessible
5- 2-79	627.28
6-10-79	627.49
7- 5-79	627.55
8- 1-79	627.61

142-084-28 BBB
Well # 369
Depth: 40.6m
Ground Elev: 647.3m
Well Head Elev: 648.4m

Date	Water Level
5-14-76	612.51
6- 2-76	612/68
7-12-76	612.59
7-26-76	612.53
8- 9-76	612.48
8-23-76	612.44
9- 9-76	612.38
9-20-76	612.35
10- 4-76	612.33
10-18-76	612.29
11- 1-76	612.27
11-24-76	612.21
12-14-76	inaccessible
1- 4-77	inaccessible
1-27-77	inaccessible
2-15-77	inaccessible
4-19-77	inaccessible
4-27-77	611.96
7-19-77	609.57
9- 6-77	610.82
10-10-77	612.10
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	inaccessible
4-20-78	inaccessible
5-23-78	612.08
6-14-78	612.08
7-21-78	611.50
8-24-78	610.93
9-22-78	611.35
10-19-78	611.53
12-12-78	inaccessible
Jan-May 79	inaccessible
6-10-79	610.76
7- 5-79	610.79
8- 1-79	612.11

142-084-21 CCC
Well # 369 A
Depth: 34.0m
Ground Elev: 647.4m
Well Head Elev: 648.4m

Date	Water Level
5-14-76	617.27
6- 2-76	617.34
7-12-76	617.34
7-26-76	617.34
8- 9-76	617.35
8-23-76	617.30
9- 9-76	617.23
9-20-76	617.23
10- 4-76	617.29
10-18-76	617.19
11- 1-76	617.22
11-24-76	617.19
12-14-76	inaccessible
1- 4-77	inaccessible
1-27-77	inaccessible
2-15-77	inaccessible
4-19-77	inaccessible
4-27-77	617.19
7-19-77	616,27
9- 6-77	616.52
10-10-77	616.51
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	inaccessible
4-20-78	inaccessible
5-23-78	616.77
6-14-78	616.77
7-21-78	616.20
8-24-78	616.81
9-22-78	616.81
10-19-78	616.78
12-12-78	inaccessible
Jan-May 79	inaccessible
6-10-79	616.74
7- 5-79	616.78
8- 1-79	616.90

Table B-2. (continued)

142-084-35 CCC
Well # 370
Depth: 32.3m
Ground Elev: 641.7m
Well Head Elev: 642.7m

Date	Water Level
5-14-76	611.22
6- 2-76	611.58
7-12-76	608.35
7-26-76	612.25
8- 9-76	611.94
8-23-76	611.49
9- 9-76	611.17
9-20-76	611.06
10- 4-76	611.01
10-18-76	611.00
11- 1-76	610.99
11-24-76	611.49
12-14-76	610.99
1- 4-77	611.00
1-27-77	611.00
2-15-77	611.00
3- 3-77	610.99
4-19-77	611.01
4-27-77	611.31
7-19-77	dry
9- 6-77	dry
10-10-77	dry
12-21-77	610.96
1-26-78	610.91
2-28-78	610.88
3-27-78	612.56
4-20-78	613.88
5-23-78	613.75
6-14-78	613.26
7-21-78	612.58
8-24-78	612.62
9-22-78	612.39
10-19-78	612.22
12-12-78	inaccessible
1979	Destroyed

142-084-35 CCC
Well # 370 A
Depth: 13.2m
Ground Elev: 641.8m
Well Head Elev: 643.2m

Date	Water Level
5-14-76	630.15
6- 2-76	630.22
7-12-76	dry
7-26-76	dry
8- 9-76	dry
8-23-76	dry
9- 9-76	dry
9-20-76	dry
10- 4-76	dry
10-18-76	dry
11- 1-76	dry
11-24-76	dry
12-14-76	dry
1- 4-77	dry
1-27-77	dry
2-15-77	dry
3- 3-77	dry
4-19-77	dry
4-27-77	dry
7-19-77	dry
9- 6-77	dry
10-10-77	dry
12-21-77	dry
1-26-78	dry
2-28-78	dry
3-27-78	dry
4-20-78	dry
5-23-78	dry
6-14-78	dry
7-21-78	dry
8-24-78	dry
9-22-78	dry
10-19-78	dry
12-12-78	dry

142-084-26 CBB
Well # 371
Depth: 35.3m
Ground Elev: 634.5m
Well Head Elev: 635.6m

Date	Water Level
5-14-76	606.29
6- 2-76	607.13
7-12-76	607.53
7-26-76	607.42
8- 9-76	607.36
8-23-76	607.30
9- 9-76	607.11
9-20-76	607.18
10- 4-76	607.15
10-18-76	607.12
11- 1-76	607.12
11-24-76	607.09
12-14-76	607.09
1- 4-77	607.00
1-27-77	606.99
2-15-77	606.97
3- 3-77	6-7.05
4-19-77	607.24
4-27-77	607.27
7-19-77	606.86
9- 6-77	607.03
10-10-77	607.05
1-28-78	607.03
2-28-78	607.05
3-27-78	607.18
4-20-78	607.95
5-23-78	607.72
6-14-78	607.58
7-21-78	606.40
8-24-78	607.44
9-22-78	607.48
10-19-78	607.38
12-12-78	607.28
3-21-79	inaccessible
5- 2-79	608.28
6-10-79	607.72
7- 5-79	607.83
8- 1-79	607.75

Table B-2. (continued)

142-084-26 CBB
Well # 371 A
Depth: 22.5m
Ground Elev: 634.5m
Well Head Elev: 635.06m

Date	Water Level
5-14-76	621.37
6- 2-76	621.52
7-12-76	621.55
7-26-76	621.52
8- 9-76	621.53
8-23-76	621.51
9- 9-76	622.46
9-20-76	621.47
10- 4-76	621.46
10-18-76	621.42
11- 1-76	621.46
11-24-76	621.45
12-14-76	621.43
1- 4-77	623.44
1-27-77	621.44
2-15-77	621.41
3- 3-76	621.43
4-19-77	621.43
4-27-77	621.43
7-19-77	621.01
9- 6-77	620.26
10-10-77	621.28
1-26-78	621.31
2-28-78	621.31
3-27-78	621.44
4-20-78	621.59
5-23-78	621.66
6-14-78	621.65
7-21-78	621.24
8-24-78	621.64
9-22-78	621.61
10-19-78	619.58
12-12-78	619.52
3-21-79	619.45
5- 2-79	621.79
6-10-79	621.80
7- 5-79	621.79
8- 1-79	621.80

142-084-16 DDD
Well # 372
Depth: 16.1m
Ground Elev: 622.0m
Well Head Elev: 623.2m

Date	Water Level
5-14-76	609.89
6- 2-76	610.00
7-12-76	609.97
7-26-76	609.94
8- 9-76	609.93
8-23-76	609.90
9- 9-76	609.86
9-20-76	609.84
10- 4-76	609.83
10-18-76	609.81
11- 1-76	609.81
11-24-76	609.78
12-14-76	609.79
1- 4-77	609.77
1-27-77	609.76
2-15-77	609.76
3- 3-77	609.75
4-19-77	609.90
4-27-77	609.91
7-19-77	dry
9- 6-77	dry
10-10-77	610.27
1-26-78	610.35
2-28-78	610.30
3-27-78	610.68
4-20-78	610.48
5-23-78	610.91
6-14-78	610.81
7-21-78	609.61
8-24-78	610.52
9-22-78	610.44
10-19-78	610.38
12-12-78	610.32
2-22-79	610.30
3-21-79	610.26
5- 2-79	610.71
6-10-79	610.74
7- 5-79	610.68
8- 1-79	610.63

142-084-16 DDD
Well # 372 A
Depth: 11.1m
Ground Elev: 621.8m
Well Head Elev: 623.1m

Date	Water Level
5-14-76	613.84
6- 2-76	613.93
7-12-76	613.96
7-26-76	613.90
8- 9-76	613.87
8-23-76	613.84
9- 9-76	613.79
9-20-76	613.77
10- 4-76	613.74
10-18-76	613.74
11- 1-76	613.74
11-24-76	613.73
12-14-76	613.70
1- 4-77	613.68
1-27-77	613.68
2-15-77	613.67
3- 3-77	613.68
4-19-77	614.02
4-27-77	613.93
7-19-77	613.41
9- 6-77	613.67
10-10-77	614.04
1-26-78	613.80
2-28-78	613.73
3-27-78	614.19
4-20-78	614.91
5-23-78	614.00
6-14-78	613.93
7-21-78	612.83
8-24-78	613.84
9-22-78	613.82
10-19-78	613.79
12-12-78	613.74
2-22-79	613.72
3-21-79	613.70
5- 2-79	614.14
6-10-79	613.96
7- 5-79	613.92
8- 1-79	613.30

Table B-2. (continued)

142-084-25 CCD
Well # 373 A
Depth: 28.4m
Ground Elev: 639.1m
Well Head Elev: 641.9m

Date	Water Level
5-14-76	614.19
6- 2-76	614.47
7-12-76	614.50
7-26 76	614.53
8- 9-76	614.50
8-23-76	614.49
9- 9-76	614.52
9-20-76	614.57
10- 4-76	614.64
10-18-76	614.70
11- 1-76	614.75
11-24-76	614.66
12-14-76	614.71
1- 4-77	inaccessible
1-27-77	inaccessible
2-15-77	614.69
4-19-77	inaccessible
4-27-77	614.67
7-19-77	dry
9- 6-77	dry
10-10-77	615.43
12-21-77	615.12
1-26-78	615.65
2-28-78	615.57
3-27-78	inaccessible
4-20-78	614.75
5-23-78	614.89
6-14-78	614.87
7-21-78	614.58
8-24-78	615.09
9-22-78	615.15
10-19-78	615.20
12-12-78	615.22
2-22-79	615.20
5- 2-79	615.23
6-10-79	615.24
7- 5-79	614.85
8- 1-79	614.89

142-084-25 CCD
Well # 373 B
Depth: 14.6m
Ground Elev: 639.1m
Well Head Elev: 640.6m

Date	Water Level
5-14-76	627.09
6- 2-76	627.22
7-12-76	627.25
7-26-76	627.24
8- 9-76	627.25
8-23-76	627.23
9- 9-76	627.22
9-20-76	627.23
10- 4-76	627.21
10-18-76	627.20
11- 1-76	627.18
11-24-76	627.19
12-14-76	627.20
1- 4-77	inaccessible
1-27-77	inaccessible
2-15-77	627.19
4-19-77	inaccessible
4-27-77	627.18
7-19-77	dry
9- 6-77	dry
10-10-77	626.32
12-21-77	626.32
1-26-78	626.32
2-28-78	626.32
3-27-78	inaccessible
4-20-78	626.46
5-23-78	626.45
6-14-78	626.43
7-21-78	625.97
8-24-78	625.45
9-22-78	626.39
10-19-78	626.39
12-12-78	626.38
2-22-79	626.36
5- 2-79	626.46
6-10-79	626.41
7- 5-79	626.42
8- 1-79	626.35

142-084-25 BBb
Well # 379
Depth: 28.4m
Ground Elev: 628.0m
Well Head Elev: 628.8m

Date	Water Level
5-14-76	602.31
6- 2-76	602.13
7-12-76	602.37
7-26-76	602.22
8- 9-76	602.15
8-23-76	602.18
9- 9-76	602.19
9-20-76	602.19
10- 4-76	602.24
10-18-76	602.25
11- 1-76	602.26
11-24-76	602.28
12-14-76	inaccessible
1- 4-77	inaccessible
1-27-77	inaccessible
2-15-77	inaccessible
4-19-77	602.44
4-27-77	602.47
7-19-77	----
9- 6-77	601.78
10-10-77	602.20
11-18-77	602.15
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	inaccessible
4-20-78	inaccessible
5-23-78	602.36
6-14-78	602.16
7-21-78	601.61
8-24-78	602.05
9-22-78	inaccessible
10-19-78	602.10
12-12-78	inaccessible
1979	Destroyed

Table B-2. (continued)

142w084-25 BBB
Well # 379 A
Depth: 9.4m
Ground Elev: 627.9m
Well Head Elev: 628.8m

Date	Water Level
5-14-76	619.46
6- 2-76	dry
7-12-76	dry
7-26-76	dry
8- 9-76	dry
8-23-76	dry
9- 9-76	dry
9-20-76	dry
10- 4-76	dry
10-18-76	dry
11- 1-76	dry
11-24-76	dry
12-14-76	inaccessible
1- 4-77	inaccessible
1-27-77	inaccessible
2-15-77	inaccessible
4-19-77	dry
4-27-77	dry
7-19-77	---
9- 6-77	dry
10-10-77	dry
11-18-77	dry
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	inaccessible
4-20-78	inaccessible
5-23-78	dry
6-14-78	dry
7-21-78	dry
8-24-78	619.62
9-22-78	inaccessible
10-19-78	dry (619.60)
12-12-78	inaccessible
1979	Destroyed

Table B-3. Hydraulic head values for piezometers in the detailed study site.

Well # 1
Depth: 41.92m
Ground Elev: 647.97m
Well Head Elev: 648.39m

Date	Water Level
12- 2-77	627.39
12-21-77	inaccessible
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	610.95
4-20-78	610.39
5-23-78	dry
6-14-78	dry (607.85)
7-21-78	dry
8-24-78	dry (607.81)
9-22-78	dry (607.75)
10-19-78	dry (608.49)
12-12-78	inaccessible
1-18-79	inaccessible
2-28-79	dry (607.76)
3-21-79	dry (607.76)
5- 2-79	dry (607.74)
6-10-79	dry (607.72)
7- 5-79	dry (607.76)
8- 1-79	dry (607.74)

Well # 2
Depth: 54.98m
Ground Elev: 647.35m
Well Head Elev: 647.35m

Date	Water Level
12- 2-77	inaccessible
12-21-77	inaccessible
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	600.16
4-20-78	599.84
5-23-78	599.97
6-14-78	599.78
7-21-78	601.01
8-24-78	599.40
9-22-78	599.37
10-19-78	598.94
12-12-78	inaccessible
1-18-79	inaccessible
2-28-79	598.56
3-21-79	598.36
5- 2-79	598.31
6-10-79	596.13
7- 5-79	597.86
8- 1-79	597.00

Well # 3
Depth: 41.65m
Ground Elev: 654.68m
Well Head Elev: 654.89m

Date	Water Level
12- 2-77	inaccessible
12-21-77	inaccessible
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	623.89
4-20-78	inaccessible
5-23-78	624.31
6-14-78	624.25
7-21-78	623.82
8-24-78	624.25
9-22-78	623.25
10-19-78	624.19
12-12-78	inaccessible
1-18-79	inaccessible
2-28-79	624.18
3-21-79	624.19
5- 2-79	624.13
6-10-79	624.04
7- 5-79	624.06
8- 1-79	624.06

Well # 6
Depth: 41.50m
Ground Elev: 644.32m
Well Head Elev: 644.61

Date	Water Level
12- 2-77	inaccessible
12-21-77	607.03
1-26-78	inaccessible
2-28-78	inaccessible
3-27-78	608.10
4-20-78	609.21
5-23-78	608.13
6-14-78	607.84
7-21-78	607.27
8-24-78	607.58
9-22-78	607.80
10-19-78	607.53
12-12-78	inaccessible
1-18-79	inaccessible
2-28-79	inaccessible
3-20-79	inaccessible
5- 2-79	610.15
6-10-79	608.26
7- 5-79	609.12
8- 1-79	608.51

Well # 9
Depth: 15.58m
Ground Elev: 629.27m
Well Head Elev: 629.74m

Date	Water Level
12- 2-77	615.27
12-21-77	615.40
1-26-78	615.41
2-28-78	615.42
3-27-78	615.42
4-18-78	615.21
5-23-78	615.44
6-14-78	615.44
7-21-78	614.48
8-24-78	615.38
9-22-78	615.41
10-19-78	615.40
12-12-78	615.34
1-18-79	615.36
2-22-79	615.39
3-21-79	615.26
5- 2-79	615.35
6-10-79	615.34
7- 5-79	615.34
8- 1-79	615.35

Well # 10
Depth: 16.66m
Ground Elev: 629.33m
Well Head Elev: 629.69m

Date	Water Level
12- 2-77	614.71
12-21-77	614.65
1-26-78	614.61
2-28-78	614.61
3-27-78	614.19
4-19-79	614.59
5-23-78	614.68
6-14-78	614.67
7-21-78	614.25
8-24-78	614.69
9-22-78	614.68
10-19-78	614.68
12-12-78	614.66
1-18-79	614.70
2-22-79	614.69
3-21-79	614.62
5- 2-79	614.63
6-10-79	614.64
7- 5-79	614.64
8- 1-79	614.73

Table B-3. (continued)

Well # 11
Depth: 16.28m
Ground Elev: 629.77m
Well Head Elev: 630.24m

Date	Water Level
12- 2-77	614.25
12-21-77	614.28
1-26-78	614.33
2-28-78	614.34
3-27-78	614.42
4-20-78	614.31
5-23-78	614.36
6-14-78	614.36
7-21-78	614.14
8-24-78	614.36
9-22-78	614.37
10-19-78	614.36
12-12-78	614.35
1-18-79	614.38
2-22-79	614.39
3-21-79	Obstructed
5- 2-79	614.26
6-10-79	614.29
7- 5-79	614.27
8- 1-79	614.29

Well # 12
Depth: 29.16m
Ground Elev: 629.01m
Well Head Elev: 629.36m

Date	Water Level
12- 2-77	604.13
12-21-77	605.60
1-26-78	606.30
2-28-78	605.01
3-27-78	606.08
4-18-78	604.98
5-23-78	605.29
6-14-78	605.55
7-21-78	604.21
8-24-78	605.85
9-22-78	606.59
10-19-78	607.11
12-12-78	607.82
1-18-79	608.15
2-28-79	608.42
3-21-79	607.21
5- 2-79	607.76
6-10-79	608.11
7- 5-79	608.15
8- 1-79	608.34

Well # 13
Depth: 13.20m
Ground Elev: 628.89m
Well Head Elev: 629.28m

Date	Water Level
12- 2-77	dry
12-21-77	dry
1-26-78	dry
2-28-78	dry
3-27-78	dry
4-19-78	dry
5-23-78	dry
6-14-78	dry
7-21-78	dry
8-24-78	dry (616.10)
9-22-78	dry (616.10)
10-19-78	616.15
12-12-78	616.15
1-18-79	dry (616.10)
2-28-79	dry (616.10)
3-21-79	616.14
5- 2-79	dry (616.10)
6-10-79	dry (616.10)
7- 5-79	dry (616.10)
8- 1-79	dry (616.10)

Well # 14
Depth: 14.94m
Ground Elev: 626.54m
Well Head Elev: 627.02m

Date	Water Level
12- 2-77	612.25
12-21-77	612.43
1-26-78	612.46
2-28-78	612.50
3-27-78	612.51
4-19-78	612.50
5-23-78	612.53
6-14-78	612.53
7-21-78	dry
8-24-78	612.54
9-22-78	612.55
10-19-78	612.54
12-12-78	612.59
1-18-79	612.61
2-28-79	612.62
3-21-79	612.59
5- 2-79	612.62
6-10-79	612.61
7- 5-79	612.62
8- 1-79	612.64

Well # 15
Depth: 27.84m
Ground Elev: 627.60m
Well Head Elev: 628.09m

Date	Water Level
12- 2-77	611.96
12-21-77	611.94
1-26-78	611.94
2-28-78	611.19
3-27-78	610.99
4-19-78	610.99
5-23-78	611.22
6-14-78	611.33
7-21-78	611.09
8-24-78	611.63
9-22-78	611.71
10-19-78	611.76
12-12-78	611.84
1-18-79	611.85
2-28-79	611.87
3-21-79	611.78
5- 2-79	611.97
6-10-79	611.85
7- 5-79	611.89
8- 1-79	611.87

Well # 16
Depth: 15.98m
Ground Elev: 627.47m
Well Head Elev: 627.91m

Date	Water Level
12- 2-77	613.94
12-21-77	614.36
1-26-78	614.37
2-28-78	614.39
3-27-78	614.37
4-19-78	614.44
5-23-78	614.53
6-14-78	614.59
7-21-78	613.59
8-24-78	614.78
9-22-78	614.80
10-19-78	614.85
12-12-78	614.95
1-18-79	615.00
2-28-79	615.06
3-21-79	614.96
5- 2-79	615.02
6-10-79	615.00
7- 5-79	615.01
8- 1-79	615.07

Table B-3. (continued)

Well # 17
Depth: 21.46m
Ground Elev: 634.21m
Well Head Elev: 634.74m

Date	Water Level
12- 2-77	614.29
12-21-77	614.28
1-26-78	614.27
2-28-78	614.29
3-27-78	614.30
4-19-78	614.29
5-23-78	614.31
6-14-78	614.30
7-21-78	613.89
8-24-78	614.33
9-22-78	614.33
10-19-78	614.32
12-12-78	614.33
1-18-79	614.34
2-22-79	Destroyed

Well # 22
Depth: 29.46m
Ground Elev: 630.44m
Well Head Elev: 630.83m

Date	Water Level
12- 2-77	610.77
12-21-77	610.83
1-26-78	610.91
2-28-78	611.04
3-27-78	611.06
4-19-78	611.10
5-23-78	611.15
6-14-78	611.16
7-21-78	610.63
8-24-78	611.23
9-22-78	611.27
10-19-78	611.49
12-12-78	611.68
1-18-79	611.67
2-22-79	611.71
3-21-79	611.74
5- 2-79	611.69
6-10-79	611.68
7- 5-79	611.69
8- 1-79	611.68

Well # 23
Depth: 18.07m
Ground Elev: 630.42m
Well Head Elev: 630.94m

Date	Water Level
12- 2-77	614.69
12-21-77	614.65
1-26-78	614.66
2-28-78	614.63
3-27-78	614.64
4-19-78	614.63
5-23-78	614.69
6-14-78	614.68
7-21-78	614.26
8-24-78	614.70
9-22-78	614.69
10-19-78	614.68
12-12-78	614.66
1-18-79	614.70
2-22-79	614.68
3-21-79	614.63
5- 2-79	614.63
6-10-79	614.65
7- 5-79	614.67
8- 1-79	614.74

Well # 24
Depth: 31.12m
Ground Elev: 633.84m
Well Head Elev: 634.21m

Date	Water Level
12- 2-77	616.06
12-21-77	inaccessible
1-26-78	616.21
2-28-78	616.50
3-27-78	616.52
4-19-78	616.52
5-23-78	dry
6-14-78	616.53
7-21-78	616.63
8-24-78	617.83
9-22-78	618.69
10-19-78	618.80
12-12-78	618.81
1-18-79	inaccessible
2-22-79	618.70
3-21-79	618.59
5- 2-79	618.44
6-10-79	618.30
7- 5-79	618.24
8- 1-79	618.14

Well # 25
Depth: 18.62m
Ground Elev: 633.95m
Well Head Elev: 633.95m

Date	Water Level
12- 2-77	dry
12-21-77	inaccessible
1-26-78	plugged
2-28-78	plugged
3-27-78	dry
4-19-78	dry
5-23-78	616.26
6-14-78	dry
7-21-78	dry
8-24-78	dry
9-22-78	dry
10-19-78	dry
12-12-78	dry
1-18-79	inaccessible
2-22-79	dry
3-21-79	plugged
5- 2-79	Destroyed

Well # 26
Depth: 20.87m
Ground Elev: 633.50m
Well Head Elev: 633.95m

Date	Water Level
12- 2-77	613.46
12-21-77	inaccessible
1-26-78	613.46
2-28-78	613.48
3-27-78	613.49
4-19-78	613.47
5-23-78	613.48
6-14-78	613.47
7-21-78	dry
8-24-78	613.50
9-22-78	613.51
10-19-78	613.50
12-12-78	613.50
1-18-79	inaccessible
2-22-79	613.51
3-21-79	613.49
5- 2-79	613.49
6-10-79	613.50
7- 5-79	613.50
8- 1-79	613.50

Table B-3. (continued)

Well # 27
Depth: 17.18m
Ground Elev: 629.96m
Well Head Elev: 630.38m

Date	Water Level
12- 2-77	dry
12-21-77	inaccessible
1-26-78	dry
2-28-78	dry
3-30-78	dry
4-19-78	dry
5-23-78	dry
6-14-78	dry
7-21-78	dry
8-24-78	dry
9-22-78	dry
10-19-78	dry
12-12-78	inaccessible
1-18-79	inaccessible
2-22-79	dry
3-21-79	inaccessible
5- 2-79	dry (613.23)
6-10-79	dry (613.23)
7- 5-79	dry (613.25)
8- 1-79	dry (613.26)

Well # 28
Depth: 22.27m
Ground Elev: 633.03m
Well Head Elev: 633.35m

Date	Water Level
12- 2-77	611.62
12-21-77	inaccessible
1-26-78	611.84
2-28-78	611.89
3-30-78	611.92
4-19-78	611.94
5-23-78	612.18
6-14-78	612.28
7-21-78	611.96
8-24-78	612.55
9-22-78	612.59
10-19-78	612.63
12-12-78	inaccessible
1-18-79	inaccessible
2-22-79	612.67
3-21-79	inaccessible
5- 2-79	612.63
6-10-79	612.69
7- 5-79	612.71
8- 1-79	Destroyed

Well # 29
Depth: 37.74m
Ground Elev: 636.61m
Well Head Elev: 637.25m

Date	Water Level
12- 2-77	608.37
12-21-77	inaccessible
1-26-78	608.35
2-28-78	606.54
3-30-78	606.85
4-19-78	605.07
5-23-78	605.75
6-14-78	605.56
7-21-78	604.48
8-24-78	605.29
9-22-78	606.23
10-19-78	606.80
12-12-78	inaccessible
1-18-79	inaccessible
2-22-79	608.12
3-21-79	inaccessible
5- 2-79	607.74
6-10-79	607.98
7- 5-79	607.87
8- 1-79	608.03

Well # 30
Depth: 25.12m
Ground Elev: 636.57m
Well Head Elev: 637.02m

Date	Water Level
12- 2-77	dry
12-21-77	inaccessible
1-26-78	dry
2-28-78	dry
3-30-78	612.64
4-19-78	613.50
5-23-78	615.68
6-14-78	613.36
7-21-78	612.65
8-24-78	612.83
9-22-78	612.64
10-19-78	612.64
12-12-78	inaccessible
1-18-79	inaccessible
2-22-79	612.09
3-21-79	inaccessible
5- 2-79	613.24
6-10-79	613.67
7- 5-79	613.64
8- 1-79	613.59

Well # 31
Depth: 31.41m
Ground Elev: 632.39m
Well Head Elev: 633.23m

Date	Water Level
7-21-78	608.68
8-24-78	608.90
9-22-78	608.99
10-19-78	608.95
12-12-78	608.94
1-18-79	608.93
2-22-79	608.95
3-21-79	609.24
5- 2-79	609.20
6-10-79	609.07
7- 5-79	609.05
8- 1-79	609.03

Well # 32
Depth: 17.24m
Ground Elev: 631.83m
Well Head Elev: 632.76m

Date	Water Level
7-21-78	616.19
8-24-78	616.05
9-22-78	616.08
10-19-78	616.08
12-12-78	616.08
1-18-79	616.09
2-22-79	616.10
3-21-79	615.90
5- 2-79	616.15
6-10-79	616.29
7- 5-79	616.30
8- 1-79	616.41

Table B-3. (continued)

Well # 33
Depth: 36.37m
Ground Elev: 631.41m
Well Head Elev: 632.26m

Date	Water Level
7-21-78	596.06
8-24-78	595.74
9-22-78	596.03
10-19-78	596.28
12-12-78	595.83
1-18-79	596.19
2-22-79	596.54
3-21-79	595.76
5- 2-79	596.15
6-10-79	596.50
7- 5-79	596.70
8- 1-79	596.95

Well # 34
Depth: 23.85m
Ground Elev: 631.07m
Well Head Elev: 631.79m

Date	Water Level
7-21-78	614.69
8-24-78	615.19
9-22-78	615.38
10-19-78	615.37
12-12-78	615.37
1-18-79	615.35
2-22-79	615.29
3-21-79	615.83
5- 2-79	616.20
6-10-79	616.14
7- 5-79	616.43
8- 1-79	616.44

Well # 35
Depth: 17.58m
Ground Elev: 630.79m
Well Head Elev: 631.78m

Date	Water Level
7-21-78	614.75
8-24-78	615.21
9-22-78	615.46
10-19-78	615.45
12-12-78	615.32
1-18-79	615.40
2-22-79	615.37
3-21-79	615.92
5- 2-79	616.29
6-10-79	616.11
7- 5-79	616.42
8- 1-79	616.41

Well # 36
Depth: 19.42m
Ground Elev: 630.25m
Well Head Elev: 631.01m

Date	Water Level
7-21-78	615.09
8-24-78	615.42
9-22-78	615.40
10-19-78	615.34
12-12-78	615.32
1-18-79	inaccessible
2-22-79	615.33
3-21-79	615.27
5- 2-79	616.43
6-10-79	616.33
7- 5-79	616.59
8- 1-79	616.63

Well # 37
Depth: 10.97m
Ground Elev: 629.94m
Well Head Elev: 631.12m

Date	Water Level
7-21-78	dry
8-24-78	dry (620.14)
9-22-78	dry (620.14)
10-19-78	620.17
12-12-78	620.17
1-18-79	inaccessible
2-22-79	froze
3-21-79	froze
5- 2-79	dry (620.19)
6-10-79	dry (620.14)
7- 5-79	dry (620.14)
8- 1-79	dry (620.14)

Well # 38
Depth: 23.68m
Ground Elev: 635.99m
Well Head Elev: 635.99m

Date	Water Level
7-21-78	615.86
8-24-78	617.52
9-22-78	617.64
10-19-78	617.48
12-12-78	617.34
1-18-79	inaccessible
2-22-79	617.24
3-21-79	617.14
5- 2-79	617.06
6-10-79	617.02
7- 5-79	616.97
8- 1-79	616.97

Table B-3. (continued)

Well # 39
Depth: 18.25m
Ground Elev: 635.06m
Well Head Elev: 635.89m

Date	Water Level
7-21-78	dry
8-24-78	dry (617.65)
9-22-78	dry (617.65)
10-19-78	dry (617.68)
12-12-78	dry (617.68)
1-18-79	inaccessible
2-22-79	dry
3-21-79	dry (617.67)
5- 2-79	dry (617.67)
6-10-79	dry (617.67)
7- 5-79	dry (617.67)
8- 1-79	dry (617.66)

Well # 40
Depth: 24.57m
Ground Elev: 635.45m
Well Head Elev: 636.46m

Date	Water Level
7-21-78	dry
8-24-78	612.46
9-22-78	613.15
10-19-78	613.57
12-12-78	613.49
1-18-79	inaccessible
2-22-79	614.11
3-21-79	612.88
5- 2-79	614.11
6-10-79	614.20
7- 5-79	614.22
8- 1-79	614.24

Well # 41
Depth: 18.93m
Ground Elev: 635.35m
Well Head Elev: 636.68m

Date	Water Level
7-21-78	dry
8-24-78	dry (617.78)
9-22-78	dry (617.77)
10-19-78	dry (617.78)
12-12-78	617.79
1-18-79	inaccessible
2-22-79	dry
3-21-79	dry (617.78)
5- 2-79	dry (617.78)
6-10-79	dry (617.76)
7- 5-79	dry (617.77)
8- 1-79	dry (617.76)

Well # 42
Depth: 25.20m
Ground Elev: 633.00m
Well Head Elev: 634.17m

Date	Water Level
7-21-78	615.37
8-24-78	615.56
9-22-78	615.59
10-19-78	616.14
12-12-78	615.85
1-18-79	inaccessible
2-22-79	615.58
3-21-79	inaccessible
5- 2-79	616.49
6-10-79	616.41
7- 5-79	616.41
8- 1-79	616.57

Well # 43
Depth: 20.73m
Ground Elev: 633.07m
Well Head Elev: 634.23m

Date	Water Level
7-21-78	614.08
8-24-78	614.47
9-22-78	626.35 (const'd)

Since Sept. of 1978 this well has been constricted at about 626.85m.

Well # 44
Depth: 22.85m
Ground Elev: 630.14m
Well Head Elev: 631.15m

Date	Water Level
7-21-78	614.30
8-24-78	614.73
9-22-78	614.73
10-19-78	614.73
12-12-78	614.73
1-18-79	614.73
2-22-79	614.74
3-21-79	614.68
5- 2-79	614.65
6-10-79	614.68
7- 5-79	614.69
8- 1-79	614.72

Table B-3. (continued)

Well # 45
Depth: 16.73m
Ground Elev: 630.08m
Well Head Elev: 630.65m

Date	Water Level
7-21-78	614.30
8-24-78	614.73
9-22-78	614.72
10-19-78	614.71
12-12-78	614.70
1-18-79	614.71
2-22-79	614.71
3-21-79	614.65
5- 2-79	614.64
6-10-79	614.66
7- 5-79	614.67
8- 1-79	614.74

Well # 46
Depth: 14.00m
Ground Elev: 630.10m
Well Head Elev: 630.73m

Date	Water Level
7-21-78	dry
8-24-78	dry (616.74)
9-22-78	dry (616.74)
10-19-78	dry (616.75)
12-12-78	dry (616.75)
1-18-79	dry (616.73)
2-22-79	dry (616.74)
3-21-79	dry (616.76)
5- 2-79	dry (616.82)
6-10-79	dry (616.74)
7- 5-79	dry (616.74)
8- 1-79	dry (616.74)

Piezometers 4, 7, 8, and 18 were destroyed prior to first reading.

Piezometers 5, 19, 20, and 21 were altered during contouring operations--require resurveying

B.2. Hydraulic Head Distribution

Figure B-4, B-5, and B-6 are potentiometric surface maps of the Kinneman Creek bed, Hagel bed, and clayey sand, respectively. The distribution of hydraulic head values in these units indicates that there is a general trend toward decreasing head values with increasing depth below the surface. The lowest hydraulic head values in the two lignites occur around the margins of the study area. The highest head values in these units occur, in general, in the vicinity of the areas of highest surface topography.

The head values in the Kinneman Creek bed indicate that the bed is either dry or slightly saturated throughout much of the southwestern portion of the study area. The Kinneman Creek bed is also dry to the northeast, at site 379. The Kinneman Creek bed is saturated in the vicinity of sites 367, 368, and 371 and constitutes a major water supply for domestic and stock wells to the west of the study area. The Hagel bed, on the other hand, appears to be a significant aquifer throughout most of the study area (Figure B-5).

The limited number of hydraulic head values in the clayey sand show a much different trend than those in the lignites (Figure B-6). The head values in this unit indicate an apparent decrease across the study area from the south to the north. There is no apparent relationship to surface topography as is the case with the lignites. However, the limited number of head values for the clayey sand unit allow for varying interpretations of the data.

B.3 Groundwater-flow Systems

Groundwater movement within the Kinneman Creek bed, Hagel bed, and clayey sand unit is indicated by the arrows on Figures B-4, B-5, and B-6. The hydraulic

2051 - Head Value in Feet Above MSL*

---- - Limit of Kinneman Creek Bed

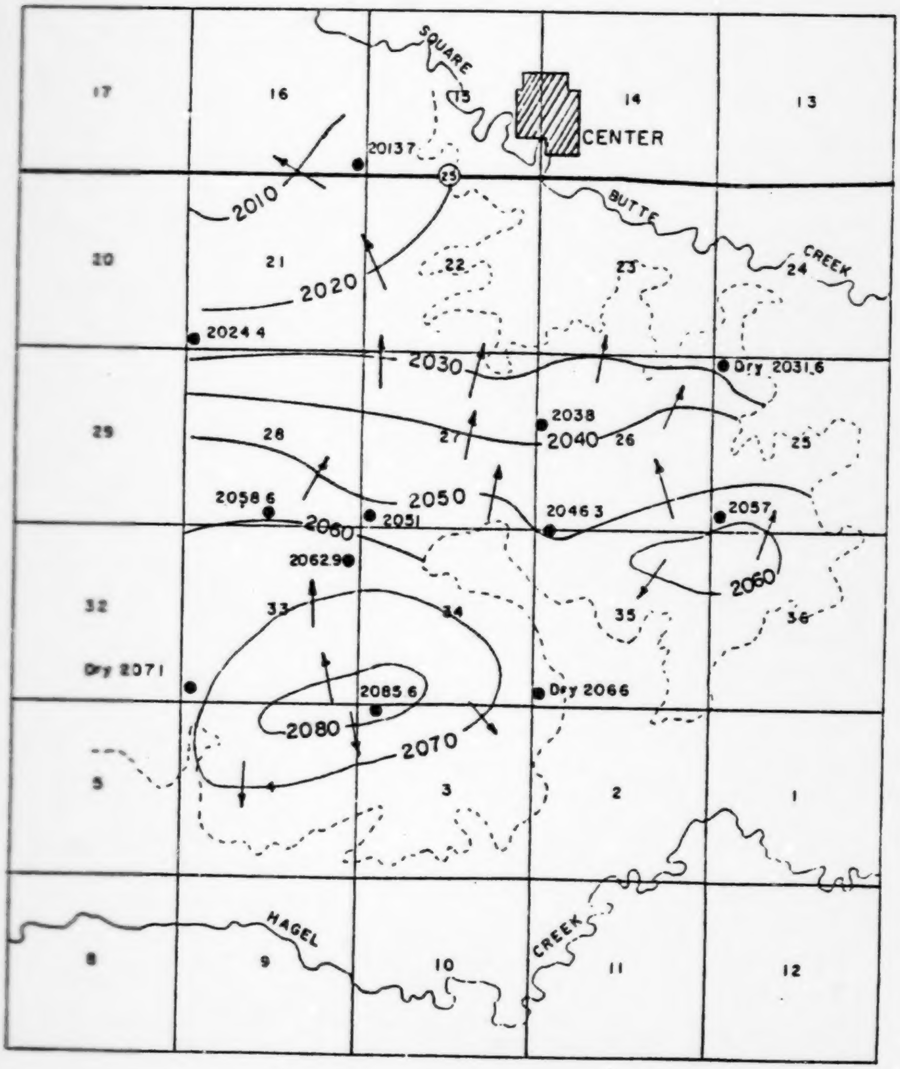
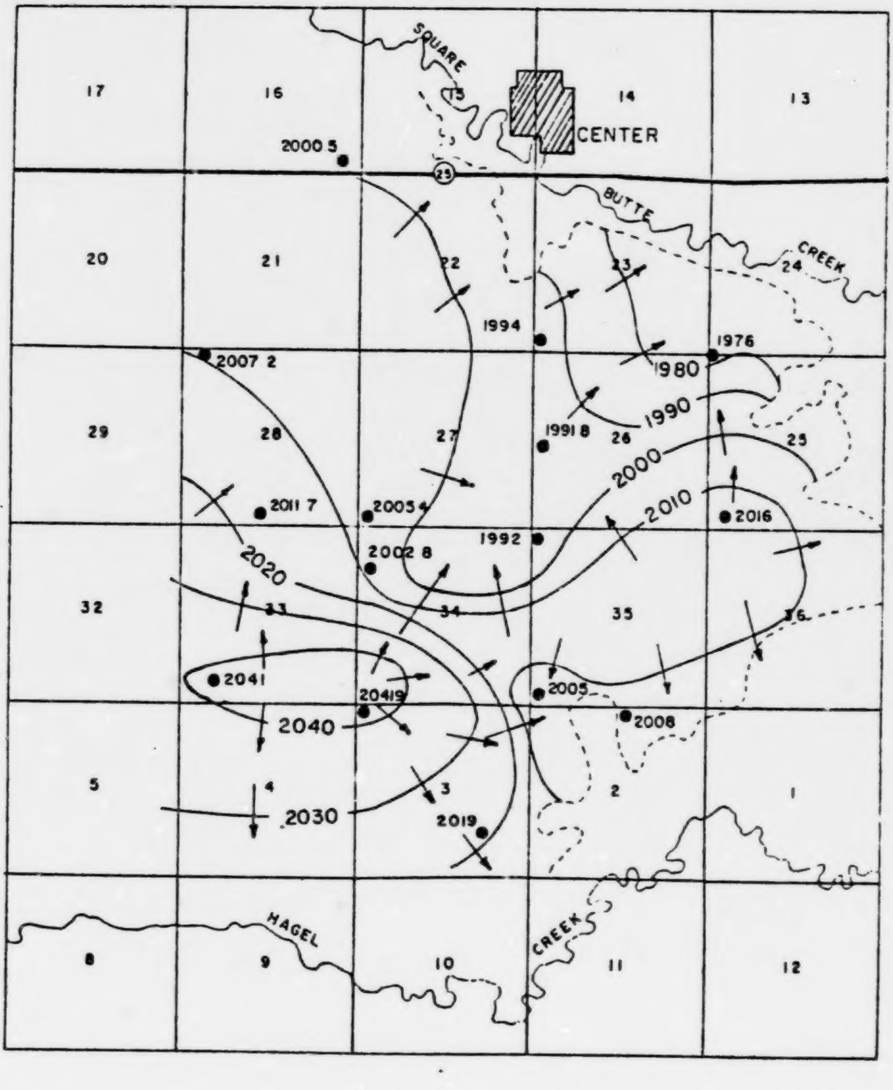

SQUARE
BUTTE
CREEK
HAGEL
CREEK
CENTER
25
17
16
15
14
13
20
21
22
23
24
29
28
27
26
25
32
33
34
35
36
5
3
2
1
8
9
10
11
12
2013.7
2024.4
Dry 2031.6
2038
2058.6
2051
2046.3
2057
2062.9
Dry 2071
2085.6
Dry 2066
2010
2020
2030
2040
2050
2060
2060
2070
2080

Figure B-4. Potentiometric Surface--Kinneman Creek Bed--Center Area.

*Divide by 3.28 to convert to metres.

1992 - Head Value in Feet Above MSL*

---- - Limit of Hagel Bed



SQUARE
CENTER
BUTTE
CREEK
HAGEL
CREEK
17
16
15
14
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29
28
27
26
25
32
33
34
35
36
5
4
3
2
1
8
9
10
11
12
25
2000 5
1994
1976
2007 2
1980
1990
1991 8
2000
2010
2011 7
2005 4
1992
2016
2020
2002 8
2041
20419
2005
2008
2040
2030
2019

Figure B-5. Potentiometric Surface--Hagel Bed--Center Area.

*Divide by 3.28 to convert to metres.

1968 - Head Value in Feet Above MSL*

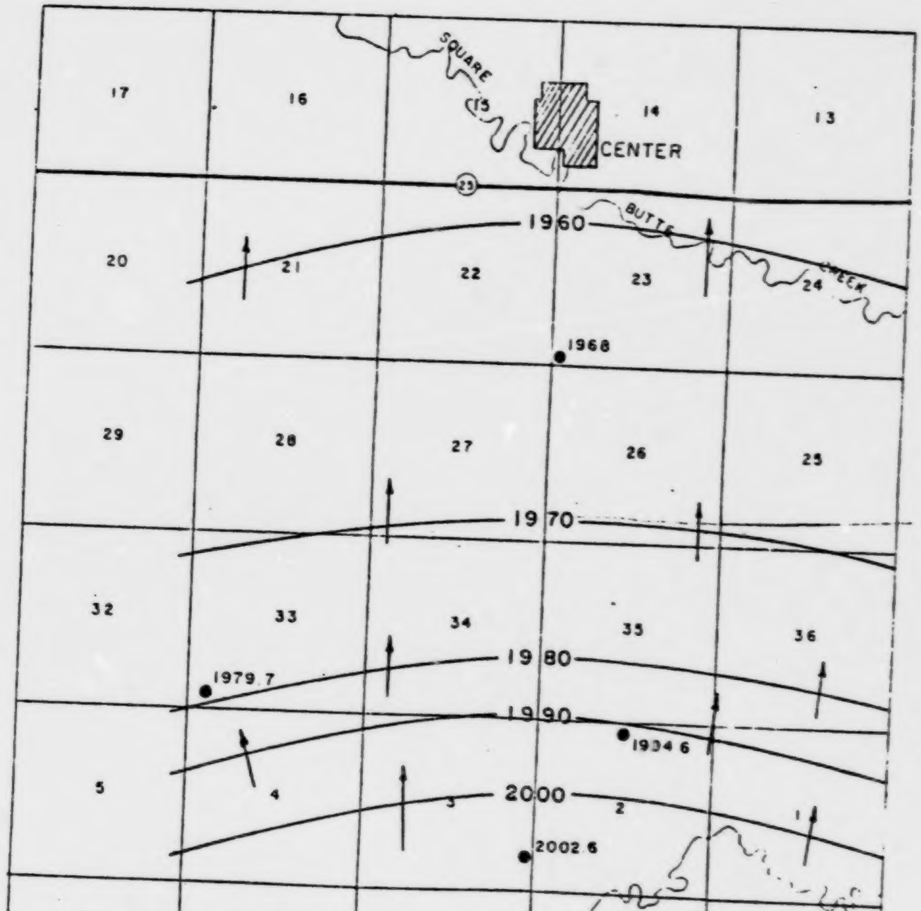
SQUARE
15
CENTER
23
BUTTE CREEK
17
16
14
13
20
21
22
23
24
1960
1968
29
28
27
26
25
1970
32
33
34
35
36
1980
1979.7
1990
1934.6
5
4
3
2
1
2000
2002.6
HAGEL
CREEK
8
9
10
11
12

Figure B-6. Potentiometric Surface--Clayey Sand--Center Area.

*Divide by 3.28 to convert to metres.

interaction between the various stratigraphic units is shown on the generalized north-south cross section (Figure B-3).

In general, the movement of groundwater in the fine-textured materials (aquitards) is vertical. The decrease in hydraulic head with depth indicates that flow within the aquitards is downward. Movement of groundwater in the sand and lignite aquifers is essentially horizontal or lateral.

Very slow downward movement of groundwater through the various aquitards supplies water to the aquifers. The aquifers, in turn, lose water by downward seepage to underlying aquitards and transmit water laterally to discharge areas along slopes or, as in the case of the clayey sand unit, to glaciofluvial valley-fill materials (Figure B-3).

The locations of recharge and discharge areas vary according to the type of flow system. Figures B-4 and B-5 indicate that the major recharge areas for both lignites correspond closely with upland areas. These are also areas of generally thin till. Discharge from the two lignites is along valley slopes, particularly along Hagel Creek and Square Butte Creek. Thus, essentially all groundwater flow within both the Kinneman Creek bed and the Hagel bed is local, originating and terminating within the study area

Groundwater flow within the clayey sand, as indicated by Figure B-6 is apparently related to a larger flow system than that which controls overlying aquifers. The general decreasing trend in hydraulic head values across the study area from south to north indicates that flow within this unit is probably controlled by the Square Butte Creek valley. Thus, the major discharge area for the clayey sand unit is apparently in the buried sand and gravel below Square Butte Creek. The major area of recharge to this unit is apparently to the south or southwest of the study area.

Hydraulic conductivity data are available from the Center area. Single-well response slug tests were run on 26 piezometers screened in undisturbed units. These data are summarized in Table B-4. In general these data agree well with values of hydraulic conductivity obtained at other study sites in North Dakota.

Hydraulic conductivity data are not available for glacial till at the Center site. Based upon data from similar sites in North Dakota, the till can be expected to have hydraulic conductivities ranging from 10^{-6} to 10^{-11} m/s. The extremely low hydraulic conductivity values obtained from the clayey sand unit are typical of highly clayey materials. Thus, although drilling samples suggest a high sand content, this unit does not constitute an aquifer in the study area.

The pre-mining physical hydrological data from the Center area indicate that this site is typical of most surface coal mining areas in the Fort Union Coal Region.

B.4 Hydrogeochemical Data

All chemical analyses of groundwater from the Center area are included in Table B-5. These data are summarized stratigraphically in Table B-6. Considerable variability in water chemistry exists in the undisturbed units. The Kinneman Creek and Hagel beds contain Na,Ca-HCO_3,SO_4 to SO_4,HCO_3 type water. Total dissolved-solids concentrations in the Kinneman Creek and Hagel beds range from 843 to 1631 mg/L and 649 to 3874 mg/L, respectively. The nonlignitic sediments underlying the Hagel bed or spoils are characterized by Na to Na,Ca-HCO_3,SO_4 to SO_4,HCO_3 type water. Total dissolved-solids concentrations in these units range from 416 to 5051 mg/L.

Table B-4. Hydraulic conductivity data from undisturbed materials--Center area.

Well #	Stratigraphic Position	Hydraulic Conductivity (m/s)
361	Hagel bed	6.74×10^{-6}
362	clayey sand	2.14×10^{-9}
362A	Hagel bed	2.45×10^{-6}
363	clayey sand	2.94×10^{-9}
363A	Hagel bed	4.47×10^{-9}
365A	Hagel bed	1.46×10^{-6}
366	Hagel bed	2.70×10^{-8}
366A	Kinneman Creek bed	2.77×10^{-7}
367	Hagel bed	6.44×10^{-9}
367A	Kinneman Creek bed	1.20×10^{-5}
368	Hagel bed	5.96×10^{-7}
368A	Kinneman Creek bed	1.07×10^{-5}
369A	Kinneman Creed bed	2.50×10^{-7}
370	Hagel bed	5.51×10^{-7}
371	Hagel bed	1.83×10^{-6}
371A	Kinneman Creek bed	7.30×10^{-7}
372	Hagel bed	6.99×10^{-9}
372A	Kinneman Creek bed	2.65×10^{-6}
373B	Kinneman Creek bed	2.40×10^{-5}
379	Hagel bed	6.85×10^{-8}
2	clayey sand	1.4×10^{-9}
6	Hagel bed	5.6×10^{-7}
12	clayey sand	4.0×10^{-10}
15	clayey sand	4.2×10^{-9}
22	clayey sand	2.5×10^{-9}
35	Hagel bed	2.27×10^{-8}

Table B-5. Chemical analyses of groundwater samples from the Center area.

Well No.	Depth (m)	Field Temp C	Field pH	Field Cond.	DO mg/1	TDS mg/1	Alk. mg/1	Total Hardness mg/1	Ca mg/1	Mg mg/1	Na mg/1	K mg/1	HCO_3 mg/1	CO_3 mg/1	Cl mg/1	SO_4 mg/1	Std. Error %
Kinneman Creek bed																	
367A	40.3	9.	6.00	2200	0.7	1539	459	731	152	63	204	13.6	560.0	---	7.2	642.7	- 1.7
368A	22.6	10.	6.52	2050	0.5	1499	712	288	54	29	441	14.3	868.6	---	3.7	232.6	12.4
371A	21.2	11.	7.49	1350	0.5	843	429	377	64	44	164	13.0	523.4	---	17.4	254.9	- 0.4
368A	22.6	16.	6.58	2100	---	1631	837	221	75	54	373	48	1021.1	---	<1.0	499	- 2.9
361A	19.7	6.5	7.01	975	0.3	838	274	---	102.5	46.9	115.0	11.4	334.3	---	16	398.8	0.1
371A	21.2	7.	7.07	1300	0.2	904	488	---	73.2	40.1	187.0	14.6	595.4	---	21.0	317.7	- 4.7
371A	21.2	11.0	6.45	1325	---	960	---	---	44	64.8	195	17	569.7	0.6	<1	245	6.0
368A	22.6	11.0	6.25	1950	---	1450	---	---	29	30.6	410	16.2	807.5	1.3	<1	313	5.7
361A	19.7	12.0	6.50	1650	---	1400	---	---	165	94.4	158	21.5	580.3	1.4	5.8	446	10.4
Hagel bed																	
365A	27.9	11.	7.0	900	0.4	652	342	95	12.1	5.7	183	4.2	412.2	----	12.5	160.0	- 6.6
373A	25.6	7.5	7.75	3000	0.3	2950	2040	---	----	----	----	----	----	----	28.0	804	---
1	40.2	8.	6.93	2200	---	1811	660	---	80.0	195.0	181	23.2	805.2	----	8.5	745	- 0.8
3	43.3	9.	7.56	1300	---	864	450	---	45.0	77.0	167	17.3	549.0	----	10.2	252	5.7
6	40.8	10.5	8.00	2150	---	1422	688	---	12.0	24.0	503	8.6	839.4	----	3.8	254	12.6
3	43.3	10	7.22	1325	0.4	912	339	---	77.5	58.0	91.7	7.8	413.0	----	13.0	281.5	4.9
5	35.7	10	7.67	920	0.2	649	437	---	8.9	2.1	188.8	5.6	533.4	----	3.0	58.9	- 3.4
6	40.8	12.5	7.42	2600	0.2	1554	668	---	22.2	10.7	498.1	6.7	815.3	----	5.3	583.9	- 3.7
30	24.4	14.5	6.75	2575	0.4	2120	700	---	222.8	144.3	167.9	8.0	854.3	----	6.5	930.4	- 4.8
35	16.8	6.0	6.50	3750	1.9	3713	446	---	337.0	202	387	16.8	544.1	----	3.3	2087	- 1.7
32	16.0	3.0	6.80	2500	0.1	2126	780	---	-----	----	----	----	951.6	----	4.7	628.5	---
35	16.8	5.0	6.90	4000	0.5	3874	471	---	328.0	153.2	336.2	12.6	574.6	----	3.8	1929	- 6.2
373A	25.6	14.0	7.50	3300	---	2270	---	---	13.8	14.1	810	17.2	1098	14.3	<1	768	4.1
365A	27.9	11.0	6.35	925	---	680	---	---	8.0	17.9	198	7.0	454.3	1.6	<1	99	0.1
Below Hagel bed																	
12	28.4	6.	7.83	2300	0.4	1584	603	---	35	16	505	12.8	735.7	----	32	522	3.1
15	27.4	3.	7.78	2800	0.2	1968	822	---	81	52	590	14.2	1002.8	----	4.0	821	1.0
22	29.6	10.	7.58	4200	0.2	2998	781	---	179	104	720	36.4	952.8	----	19.5	1350	5.8
24	30.5	5.	8.00	2200	0.3	1902	1314	---	36	21	697	10.0	1603.1	----	10.6	384	- 0.7
29	36.6	6.	7.94	1875	0.2	1774	1426	---	21	10	683	9.8	1739.7	----	7.6	229	- 2.5

Table B-5. (continued)

Well No.	NO$_3$ mg/l	F mg/l	PO$_4$ mg/l	SO$_3$ mg/l	Fe µg/l	Mn µg/l	Cu µg/l	Cd µg/l	Pb µg/l	Hg µg/l	Se µg/l	As µg/l	^{3}H	DOC mg/l	Date	Location
Kinneman Creek bed																
367A	<0.1	<0.1	---	---	1300	461	9.0	0.3	13.8	---	---	----	14± 9	20.1	05-13-77	142-084-27 CCC
368A	<0.1	<0.1	---	---	562	130	11.7	0.3	11.5	---	---	----	13± 9	----	05-13-77	142-084-33 ADA
371A	0.11	<0.1	---	---	45	259	14.0	0.2	6.4	---	---	----	29± 9	9.5	05-13-77	142-084-26 CBB
368A	----	0.1	---	---	363	95	21	3	---	---	---	----	13± 9	24.7	08-24-77	142-084-33 ADA
361A	5.4	0.1	---	8.0	190	400	----	1.2	2.0	0.0	3.4	----	-----	----	03-02-78	142-084-35 BBB
371A	1.5	0.1	---	2.0	350	610	----	0.8	2.0	0.2	1.6	1.0	-----	----	03-02-78	142-084-26 CBB
371A	6.5	----	---	---	251	---	----	---	---	---	---	----	-----	----	06-11-79	142-084-26 CBB
368A	0.34	----	---	---	657	---	----	---	---	---	---	----	-----	----	06-11-79	142-084-33 ADA
361A	0.16	----	---	---	638	---	----	---	---	---	---	----	-----	----	06-12-79	142-084-35 BBB
Hagel bed																
365A	<0.1	0.3	---	---	147	598	9.4	1.3	5.2	---	---	----	4± 9	6.9	06-28-77	142-084-33 CCC
373A	---	0.5	---	20.5	---	---	----	---	---	---	---	----	-----	----	03-01-78	142-084-25 CCC
1	---	----	---	---	530	1313	----	<1.0	20.9	0.5	0.0	----	-----	----	03-28-78	
3	---	----	---	---	220	306	----	<1	76.5	0.6	---	----	-----	----	03-28-78	
6	---	----	--	2.0	210	153	----	<2	21.9	0.7	---	----	-----	----	03-30-78	
3	0.17	0.1	<0.1	2.0	130	360	----	<1	0.5	0.6	0.0	1.1	-----	----	07-05-78	
5	0.33	0.1	<0.1	0.5	150	60	----	<1	3.0	0.5	0.0	6.5	-----	----	07-05-78	
6	0.25	0.7	<0.1	---	70	230	----	<1	4.9	0.5	1.6	1.9	-----	----	07-05-78	
30	1.24	<0.1	<0.1	6.5	580	2040	----	<1	0.4	0.7	2.9	4.2	-----	----	07-05-78	
35	0.27	0.0	<0.05	4.0	90	2520	----	4.4	7.1	0.3	0.4	2.2	-----	----	11-16-78	
32	---	<0.1	<0.05	---	---	---	----	---	---	---	---	----	-----	----	02-28-79	
35	0.59	<0.1	<0.05	3.5	100	2750	----	1.2	---	<0.3	<2	<2	-----	----	02-27-79	
373A	5.0	----	---	---	---	---	----	---	---	---	---	----	-----	----	06-11-79	142-084-25 CCC
365A	0.10	----	---	---	126	---	----	---	---	---	---	----	-----	----	06-11-79	142-084-33 CCC
Below Hagel bed																
12	3	1.0	---	1.5	420	429	----	3.8	33.3	4.6	4.5	7.6	-----	----	02-01-78	
15	1.7	0.6	---	1.0	240	388	----	0.8	12.5	0.4	4.4	4.0	-----	----	01-31-78	
22	1.02	0.4	---	1.0	420	440	----	3.2	13.3	3.0	4.5	5.7	-----	----	01-31-78	
24	3	0.9	---	1.5	340	222	----	0.2	28.7	2.2	4.5	5.2	-----	----	02-01-78	
29	1.6	0.9	---	1.5	480	207	----	1.0	38.3	3.0	4.2	14.0	-----	----	02-01-78	

Table B-5. (continued)

Well No.	Depth (m)	Field Temp. C	Field pH	Field Cond.	DO mg/l	TDS mg/l	Alk. mg/l	Total Hardness mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	CO_3 mg/l	Cl mg/l	SO_4 mg/l	Std. Error %
Below Hagel bed (cont)																	
360A	33.0	7.	7.64	600	0.3	416	308	---	26.9	7.9	108.8	10.6	375.8	----	20	74.4	- 8.4
360A	33.0	10.	8.28	1350	---	538	318	318	19.4	7.9	109	8.6	388.0	----	107.2	31.4	-20.8
2	55.5	8.5	7.98	2700	---	1891	565	---	49.0	34.0	540	33.0	689.3	----	16.5	870	- 0.5
12	28.4	5.5	7.94	2250	---	1541	690	---	13.0	62.0	515	11.1	841.8	----	12.0	566	4.6
15	27.4	5.	8.12	3000	---	2114	896	---	42.0	28.0	644	16.6	1093.1	----	5.0	861	- 4.5
22	29.6	6.	6.86	4000	---	3038	901	---	70.0	186.0	723	25.0	1099.2	----	8.5	1510	1.2
24	30.5	9.	8.03	3000	---	1910	1475	---	19.0	28.0	730	11.1	1799.5	----	7.8	339	- 2.1
29	36.6	10.	7.98	2700	---	1726	1592	---	8.0	12.0	710	9.3	1942.2	----	5.0	154	- 3.9
2	55.5	14.	7.33	1500	0.3	1124	403	---	28.3	18.9	244.8	8.2	491.4	----	15.8	383.7	0.2
12	28.4	9.5	7.70	2400	0.2	1617	732	---	22.7	10.1	483.3	6.3	893.0	----	12.6	524.7	- 5.7
15	27.4	9.5	7.20	3100	0.7	2163	839	---	59.6	39.0	597.8	8.0	1023.8	----	4.5	860.0	- 3.6
22	29.6	10.5	7.71	4500	0.3	3200	889	---	98.1	66.5	796.2	7.6	1084.8	----	4.0	1609.8	- 6.4
24	30.5	9.	7.94	2550	0.4	1933	1361	---	11.8	12.4	685.4	6.1	1660.2	----	7.8	302.5	- 3.3
29	36.6	12.5	7.79	2700	0.3	1731	1388	---	5.3	6.0	672.6	6.4	1692.9	----	9.0	140.9	- 1.2
31	30.5	11.	7.70	3000	0.3	----	1226	---	71.4	34.6	701.3	8.6	1496.0	----	3.4	502.9	2.8
34	22.9	11.	7.23	4000	1.2	----	1056	---	158.7	90.2	796.7	7.7	1288.2	----	2.0	1275.0	2.5
36	18.0	11.	6.38	4100	0.4	----	760	---	323.9	159.2	561.6	7.4	926.6	----	2.9	1894.4	- 0.8
38	23.2	10.5	6.64	6000	0.1	----	1145	---	191.5	159.4	1311	7.6	1397.0	----	4.9	2662.4	0.9
42	22.9	10	6.81	1900	0.2	----	732	---	99.1	49.6	400.0	7.4	893.4	----	5.3	444.9	5.1
44	24.4	8.5	5.86	3900	1.7	----	686	---	124.5	85.2	738.7	7.5	836.4	----	7.2	1519.4	0.0
31	30.5	7.0	7.70	3300	1.4	2063	1200	---	46.5	29.0	700	9.5	1464.0	----	3.5	437	3.2
34	22.9	7.0	6.85	4000	1.6	2845	1007	---	183.6	87.0	689	12.7	1228.5	----	2.2	1190	1.8
36	18.0	5.5	6.85	4400	1.6	3749	691	---	361.8	171.0	5.9	14.0	843.0	----	3.3	1904	-24.1
38	23.2	7.0	7.25	6500	0.8	5056	1133	---	177.8	122.0	1299	15.9	1382.3	----	4.8	2618	- 1.0
40	24.4	7.0	9.25	3800	0.5	2769	328	---	71.2	19.2	814	11.7	400.2	----	9.0	1422	5.7
42	22.9	8.0	7.85	2200	0.2	1467	729	---	59.9	40.5	425	9.5	889.4	----	9.3	415	3.2
44	24.4	5.5	6.90	4000	1.1	2893	695	---	140.4	77.0	732	20.7	847.9	----	7.5	1386	3.1
12	28.4	6.5	8.25	2300	0.4	1560	745	---	122.	6.8	448.3	3.5	908.3	----	9.5	437.8	3.9
15	27.4	7.0	7.70	3000	0.4	2092	745	---	76.7	33.9	560.3	8.9	908.9	----	2.6	754.7	0.9
22	29.6	6.0	7.25	3200	0.7	2195	915	---	43.2	28.7	681.0	8.0	1116.8	----	3.8	716.4	1.5
24	30.5	7.0	8.20	3000	0.1	1908	1330	---	20.8	9.9	715.5	5.4	1622.4	----	9.0	265.6	1.1
31	30.5	6.5	7.35	3000	2.7	2127	1229	---	38.2	24.8	646.6	8.6	1499.7	----	3.8	364.4	0.0
33	35.1	3.0	7.70	3600	0.6	2464	1158	---	24.2	10.8	896.6	8.5	1412.8	----	6.8	814.2	1.2
40	24.4	8.0	8.65	4000	0.0	2799	492	---	40.6	13.8	844.8	10.9	600.0	----	9.3	1379.4	1.7
42	22.9	8.0	7.50	2300	0.5	1492	752	---	49.3	33.5	474.1	10.6	917.4	----	7.7	453.9	2.7
362	25.0	11.0	7.30	2100	---	1430	----	---	3.5	9.2	525	8.0	1013.9	12.6	<1	180	7.0

Table B-5. (continued)

Well No.	NO_3 mg/l	F mg/l	PO_4 mg/l	SO_3 mg/l	Fe µg/l	Mn µg/l	Cu µg/l	Cd µg/l	Pb µg/l	Hg µg/l	Se µg/l	As µg/l	^3H	DOC mg/l	Date	Location
Below Hagel bed (cont)																
360A	0.85	0.3	---	16.0	350	250	----	1.8	10.2	0.0	2.8	0.0	-----	----	03-02-78	
360A	<0.1	0.4	---	---	96	151	5.1	0.3	4	---	----	----	48±10	----	06-29-77	
2	---	----	---	---	270	49	----	<1	21.9	0.3	2.1	----	-----	----	03-28-78	
12	---	----	---	---	220	271	----	<1	17.6	0.5	0.0	6.3	-----	----	03-28-78	
15	---	----	---	---	240	128	----	<1	16.2	0.3	0.0	2.8	-----	----	03-28-78	
22	---	----	---	---	320	164	----	<1	16.7	1.8	----	----	-----	----	03-28-78	
24	---	----	---	8.5	470	237	----	<1	9.2	0.6	----	----	-----	----	03-28-78	
29	---	----	---	4.0	400	136	----	<1	20.5	0.5	----	----	-----	----	03-30-78	
2	55.8	----	<0.1	55.0	320	260	----	1.1	5.7	0.0	1.6	4.9	-----	----	07-05-78	
12	0.13	1.6	<0.1	22.0	160	270	----	<1	1.6	0.1	1.8	2.8	-----	----	07-06-78	
15	0.0	0.3	<0.1	13.0	90	200	----	<1	3.5	0.5	3.9	0.4	-----	----	07-07-78	
22	0.11	0.2	<0.1	4.5	140	180	----	<1	7.9	0.8	1.8	0.0	-----	----	07-07-78	
24	0.14	1.7	<0.1	2.2	150	300	----	<1	1.4	0.3	1.3	4.9	-----	----	07-07-78	
29	0.19	1.7	<0.1	15.0	190	100	----	<1	0.9	0.7	1.1	2.1	-----	----	07-05-78	
31	0.12	0.5	<0.05	1.0	90	240	----	7.9	3.9	0.0	6.1	0.3	-----	----	08-17-78	
34	0.09	0.1	<0.05	1.0	590	380	----	11.4	6.5	0.0	1.7	0.9	-----	----	08-21-78	
36	2.8	0.1	<0.05	1.0	470	1080	----	3.6	8.8	0.3	2.2	1.5	-----	----	08-17-78	
38	0.46	0.1	<0.05	1.0	240	370	----	23.7	12.2	0.0	3.0	0.0	-----	----	08-17-78	
42	0.42	0.4	<0.05	1.0	120	120	----	14.6	3.2	0.3	6.1	1.8	-----	----	08-17-78	
44	0.33	0.2	<0.05	1.5	70	370	----	25.2	11.2	0.0	4.3	2.4	-----	----	08-22-78	
31	0.06	0.1	<0.05	1.0	520	310	----	<1	9.8	0.7	0.4	2.3	-----	----	11-15-78	
34	0.11	0.0	<0.05	2.0	320	410	----	<1	7.3	0.8	0.4	1.6	-----	----	11-14-78	
36	0.10	0.0	<0.05	1.0	440	1040	----	3.0	7.2	0.6	0.0	2.8	-----	----	11-15-78	
38	0.20	0.1	<0.05	1.0	440	580	----	3.8	29.3	0.7	0.0	2.3	-----	----	11-16-78	
40	0.19	1.3	0.11	2.5	20	150	----	3.0	38.8	0.2	0.9	37.6	-----	----	11-16-78	
42	0.02	0.4	<0.05	10.0	100	240	----	<1	8.5	0.7	0.9	1.3	-----	----	11-16-78	
44	0.10	0.1	<0.05	1.0	330	380	----	1.0	14.2	0.4	0.0	3.6	-----	----	11-15-78	
12	0.43	2.3	0.07	15.5	50	140	----	1.2	---	<0.3	<2	10.7	-----	----	02-26-79	
15	0.14	0.2	<0.05	2.0	120	120	----	1.1	---	<0.3	<2	<2	-----	----	02-26-79	
22	0.52	0.3	<0.05	2.0	150	180	----	<1	---	<0.3	<2	<2	-----	----	02-27-79	
24	0.17	1.1	<0.05	21.0	60	300	----	<1	---	<0.3	<2	<2	-----	----	02-26-79	
31	0.06	0.3	<0.05	4.0	130	220	----	<1	---	0.5	<2	2.5	-----	----	02-28-79	
33	0.56	1.1	<0.05	12.0	210	110	----	12.3	---	0.4	<2	7.3	-----	----	02-27-79	
40	0.24	1.4	0.08	3.0	40	130	----	23.5	---	<0.3	<2	24.1	-----	----	02-26-79	
42	0.06	0.5	<0.05	4.0	100	410	----	<1	---	<0.3	<2	<2	-----	----	02-26-79	
362	0.50	----	---	----	103	---	----	---	---	---	----	----	-----	----	06-11-79	141-084-02 ABB

Table B-5. (continued)

Well No.	Depth (m)	Field Temp. C	Field pH	Field Cond.	DO mg/1	TDS mg/1	Alk. mg/1	Total Hardness mg/1	Ca mg/1	Mg mg/1	Na mg/1	K mg/1	HCO3 mg/1	CO3 mg/1	Cl mg/1	SO4 mg/1	Std. Error %
Spoils																	
17	20.7	2.	6.74	2300	---	1950	1296	---	----	----	----	----	1580	----	14	628.7	----
16	15.2	4.5	6.80	4000	0.6	4335	298	---	519.0	342.0	300.0	34.0	363.6	----	21.0	1059.9	40.8
9	15.2	9.5	6.31	3100	---	3182	1200	---	----	----	----	----	1464.	----	3.8	1318	----
10	15.9	8.	12.21	6750	---	5682	353	---	180.0	95.0	1580	196.0	430.7	----	17.4	3491	6.1
11	15.9	9.	7.32	5000	---	5338	1732	---	----	----	----	----	2113.0	----	6.2	2520	----
23	17.4	6.	7.65	4000	---	3866	943	---	190.0	393.0	419	31.0	1150.5	----	8.0	1872	2.4
9	15.2	14.	6.50	3500	0.8	3221	1086	---	447.0	200.0	256.8	8.1	1325.5	----	2.5	1396.2	- 0.7
10	15.9	11.5	11.74	>8000	0.4	555	715	---	28.2	0.1	1340.0	9.7	872.5	----	19.8	3015.5	-12.8
11	15.9	12.5	6.71	>8000	1.1	----	----	---	226.1	147.0	1118.0	8.8	----	----	---	----	----
14	14.9	14.5	6.64	5200	0.6	----	----	---	220.0	164.9	761.6	8.0	----	----	---	----	----
16	15.2	10.	6.95	4500	0.9	4189	868	---	424.2	314.5	251.0	9.0	1058.5	----	10.7	2088.8	- 2.5
17	20.7	16.5	6.93	1830	1.4	1599	723	---	210.0	103.5	200.0	8.4	882.3	----	4.2	686.8	- 1.7
23	17.4	11.5	6.62	4250	1.3	3734	857	---	397.7	200.0	363.4	8.1	1045.3	----	9.7	1770.3	- 1.8
28	22.0	15.	6.40	3100	0.6	2806	802	---	308.6	211.6	121.9	7.8	978.0	----	11.4	1283.5	- 5.8
43	19.8	11.5	6.65	3900	1.4	----	609	---	432.3	431.2	89.5	7.5	742.5	----	8.0	2189.5	2.6
10	15.9	6.0	12.1	>8000	1.3	5425	485	---	32.8	0.3	1550	198.4	591.7	----	27.0	3213	- 2.1
9	15.2	4.0	6.95	3800	1.0	3060	1032	---	379.8	203.6	310.3	18.6	1259.0	----	2.5	1315.2	1.6
10	15.9	4.5	11.85	8000	3.5	5715	500	---	30.8	1.3	1517	198.3	610.	----	26.5	3607.3	- 8.3
14	14.9	8.0	6.95	3200	0.4	2259	1145	---	----	----	----	----	1396.9	----	7.6	565.8	----
16	15.2	6.0	7.10	3500	0.2	3104	748	---	314.0	207.4	250.0	24.4	912.6	----	7.7	1457.8	- 1.4
23	17.4	5.0	6.45	4200	0.5	3840	843	---	402.2	218.9	413.8	17.8	1028.9	----	8.8	1757.5	2.6

Table B-5. (continued)

Well No.	NO3 mg/l	F mg/l	PO4 mg/l	SO3 mg/l	Fe µg/l	Mn µg/l	Cu µg/l	Cd µg/l	Pb µg/l	Hg µg/l	Se µg/l	As µg/l	^3H	DOC mg/l	Date	Location
Spoils																
17	---	0.2	---	---	---	---	----	---	---	---	----	----	-----	----	03-01-78	
16	1.75	0.3	---	2.0	220	3100	----	1.7	1.0	0.2	2.2	0.4	-----	----	03-01-78	
9	---	---	---	---	---	---	----	---	---	---	----	----	-----	----	03-27-78	
10	---	---	---	---	250	14	----	<2	55.8	---	----	----	-----	----	03-27-78	
11	---	---	---	---	---	---	----	---	---	---	----	----	-----	----	03-27-78	
23	---	---	---	---	130	2476	----	<1	22.1	---	----	----	-----	----	03-28-78	
9	0.14	<0.1	<0.1	3.0	510	710	----	<1	0.4	1.3	1.8	1.9	-----	----	07-06-78	
10	1.13	1.7	0.12	8.0	20	10	----	<1	33.1	0.8	3.8	171.8	-----	----	07-06-78	
11	---	---	---	8.0	20	410	----	<1	8.2	0.0	0.9	7.0	-----	----	07-06-78	
14	---	---	---	---	60	1480	----	<1	11.2	0.3	2.1	5.6	-----	----	07-06-78	
16	0.52	<0.1	<0.1	2.5	1220	2290	----	<1	0.5	0.5	2.4	2.4	-----	----	07-07-78	
17	0.24	0.1	<0.1	5.0	70	1170	----	<1	0.0	0.2	0.0	5.4	-----	----	07-07-78	
23	0.63	<0.1	<0.1	2.0	780	1010	----	<1	0.5	0.5	0.5	10.1	-----	----	07-07-78	
28	0.48	<0.1	<0.1	6.0	110	890	----	<1	0.5	0.5	1.1	1.9	-----	----	07-05-78	
43	0.44	0.1	<0.05	4.0	100	3	----	2.4	4.5	0.0	4.8	1.2	-----	----	08-21-78	
10	0.60	1.4	0.12	3.0	30	24	----	3.6	58.0	0.7	13.6	204.6	-----	----	11-10-78	
9	0.42	<0.1	<0.05	3.0	940	4070	----	8.8	---	<0.3	<2	<2	-----	----	02-24-79	
10	0.13	1.7	0.08	3.0	110	20	----	4.7	---	<0.3	8.2	97.8	-----	----	02-24-79	
14	---	0.3	<0.05	---	---	---	----	---	---	---	----	----	-----	----	02-26-79	
16	0.24	<0.1	<0.05	2.5	90	2710	----	<1	---	<0.3	<2	2.1	-----	----	02-26-79	
23	0.60	<0.1	<0.05	1.5	1430	2140	----	1.7	---	<0.3	<2	4.9	-----	----	02-27-79	

Table B-6. Summary of groundwater chemical data from the Center area.

	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	Cl mg/l	SO_4 mg/l	TDS mg/l	NO_3 mg/l	F mg/l	PO_4 mg/l	Mn µg/l	Fe µg/l	Cu µg/l	Cd µg/l	Pb µg/l	Hg µg/l	Se µg/l	As µg/l	^3H
Kinneman Creek bed																				
$\bar{x}$	84.3	51.9	249.7	18.8	651.1	8.1	372.2	1229.3	1.8	0.1	---	325.8	484.0	13.9	1.0	7.1	0.1	2.5	1.0	17.3
s	47.0	20.3	122.7	11.3	208.7	8.0	137.5	333.3	2.6	0.0	---	200.3	369.4	5.1	1.1	5.4	0.1	1.3	---	7.9
n	9	9	9	9	9	9	9	9	8	6	---	6	9	4	6	5	2	2	1	4
Hagel bed																				
$\bar{x}$	97.3	75.3	309.3	11.3	657.7	5.9	679.1	1828.4	0.9	0.2	0.0	1033.0	213.9	9.4	1.1	15.6	0.5	0.8	2.8	4±9
s	125.3	77.2	208.4	6.0	217.6	4.3	683.6	1090.8	1.6	0.2	0.0	1042.9	175.0	---	1.2	24.2	0.2	1.1	2.1	---
n	12	12	12	12	12	12	12	14	9	9	7	10	11	1	10	9	9	7	6	1
Below Hagel bed																				
$\bar{x}$	79.4	49.2	627.4	11.3	1073.2	10.4	843.2	2116.8	2.1	0.6	0.0	291.6	244.6	5.1	3.9	13.3	0.7	2.0	4.8	48±10
s	80.9	49.4	251.2	6.7	433.7	16.6	660.9	870.1	9.4	0.6	0.0	213.5	155.8	---	6.8	10.5	1.0	1.8	7.4	----
n	41	41	41	41	41	41	41	35	35	33	27	40	41	1	40	32	39	36	35	1
Spoils (not including well # 10)																				
$\bar{x}$	343.9	241.4	373.5	14.7	1153.4	8.4	1460.7	3547.8	0.6	0.1	0.0	436.9	1727.6	---	1.5	4.9	0.3	1.6	3.7	----
s	106.5	98.2	279.3	9.6	404.5	4.8	581.3	1443.6	0.5	0.1	0.0	492.3	1180.3	---	2.3	7.2	0.4	1.3	2.9	----
n	13	13	13	13	15	15	15	18	10	12	10	13	13	---	13	10	12	12	12	----
Well 10																				
$\bar{x}$	68.0	24.2	1496.8	150.6	626.2	22.7	3331.7	4344.3	0.6	1.6	0.1	102.5	17.0	---	2.5	49.0	0.6	8.5	158.1	---
s	74.7	47.2	107.6	93.9	182.9	4.8	268.0	2529.5	0.5	0.2	0.0	106.3	6.2	---	2.0	13.8	0.4	4.9	54.7	---
n	4	4	4	4	4	4	4	4	3	3	3	4	4	---	4	3	3	3	3	---

When calculating $\bar{x}$ and s if a value was "less than" then ½ of that value was used.

$\bar{x}$ = mean value
s = standard deviation
n = no. of measurements

B-5. Physical Hydrological Characteristics of the Spoils

Figure B-7 is a potentiometric surface map for the base of the spoils. Head values from two piezometers screened in unmined lignite (Hagel Bed), and thus at the same position as the basal portion of the spoils, were also used to construct Figure B-7. Although varying interpretations can be made, it appears that recharge is occurring in the spoils in section 36. Groundwater movement in the base of the spoils is largely toward the south and southwest. A smaller component appears to be toward the north. The base of the spoils is saturated in much of section 36. Saturation is less widespread in section 35. However, head values in these wells show a fairly consistent rise with time suggesting that equiligrium conditions have yet to be established in the basal portion of the spoils. Tritium and oxygen-18 samples were collected from 22 piezometers in sections 35 and 36. These data substantiate the conclusion that recharge is occurring through the spoils.

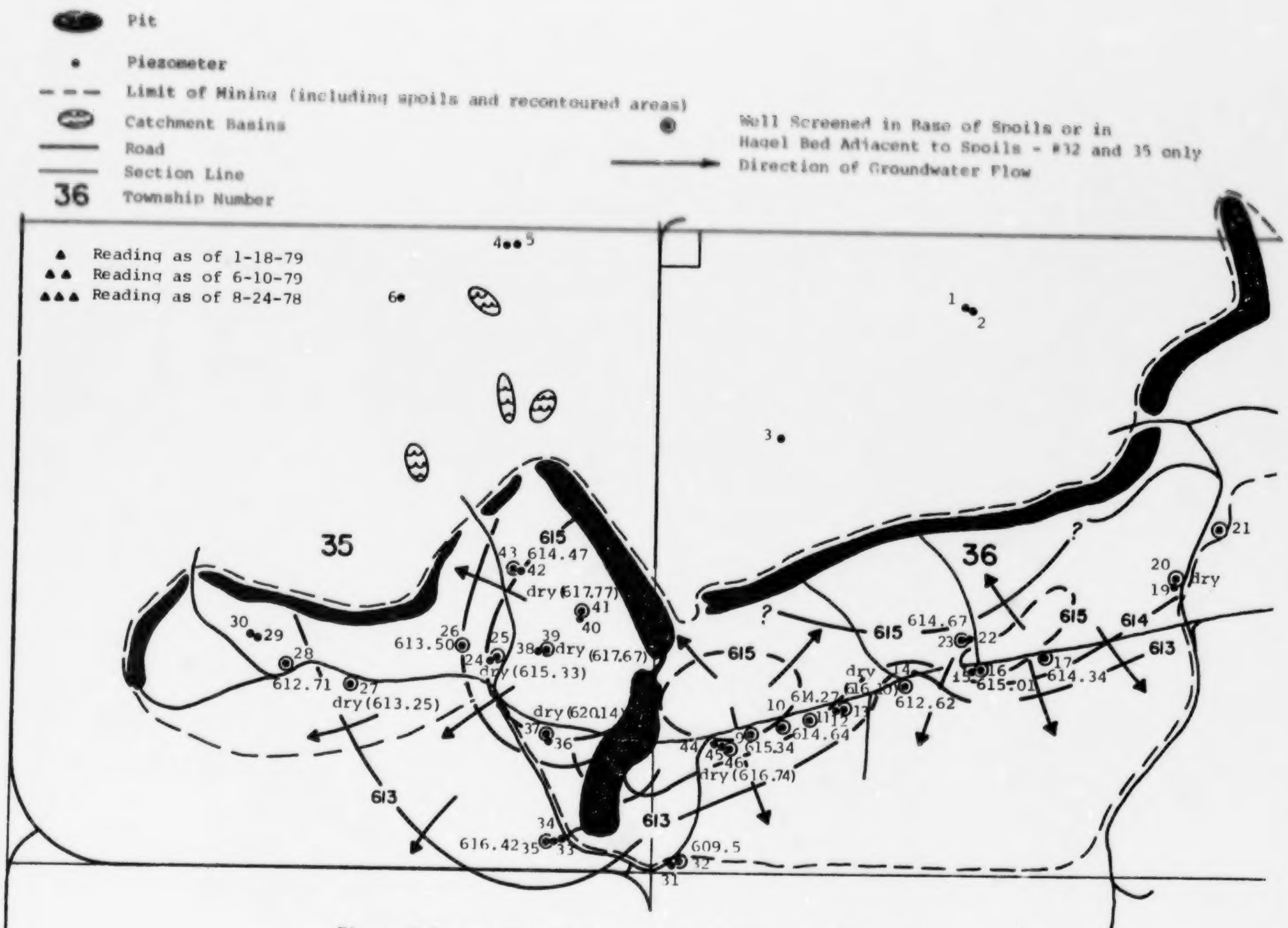
Pit
Piezometer
Limit of Mining (including spoils and recontoured areas)
Catchment Basins
Road
Section Line
36 Township Number
Well Screened in Base of Spoils or in Hagel Bed Adjacent to Spoils - #32 and 35 only
Direction of Groundwater Flow
▲ Reading as of 1-18-79
▲▲ Reading as of 6-10-79
▲▲▲ Reading as of 8-24-78
35
36
1
2
3
4
5
6
615
43 614.47
42
dry (617.77)
41
40
26
613.50
25
24
dry (615.33)
39
38 dry (617.67)
30
29
28
612.71
27
dry (613.25)
dry (620.14)
37
36
613
34
616.42 35
33
613
609.5
32
31
44
45
46
dry (616.74)
9
615.34
10
614.27
614.64
11
12
13
dry
14
(616.10)
612.62
615
?
615
614.67
23
22
15
16
615.01
17
614.34
615
614
613
?
20
19 dry
21

Figure B-7. Potientiometric Surface - Base of Spoils 7-5-79

APPENDIX C. SAMPLING AND ANALYTICAL PROCEDURES

C-1. Well Construction

Wells at the Center site were in general not deeper than 125 feet to 150 feet. The borehold diameters were 5 1/8" to 6". All new installations were geophysically logged and Gamma and Gamma Density logs recorded. The well installation procedure consisted of five steps:

1) Screen and pipe assembly.
2) Screen and pipe insertion into the borehole.
3) Circulation
4) Gravel Packing.
5) Backfilling and Sealing.

All installations were made using 2" PVC pipe, 160 P.S.I. strength. Commercially produced slotted PVC pipe (2" x 20 ft, sawed to the appropriate lengths were used for all well screens. Complete assembly of the pipe and screen was done before insertion into the borehole. The pipes were joined together in 20 foot sections with sleeve couplings and cementing glue. The pipes were cut so that, with the screen at its proper depth, the top of the pipe are 2 to 3 feet above ground level. A male or female threaded adaptor was glued on the supper end of the pipe. Clean water was pumped down the pipe to clear the screen and the screened interval of mud and cuttings. A pea gravel pack was placed around the screen (5/16" pea-gravel). The portion of the hole above the pea-gravel was grouted to the surface.

C-1. Water Sampling

The sampling of each groundwater well was done once every four months, beginning immediately after sludge disposal. Prior to sampling the wells, water levels in the wells are recorded and a probe placed in the wells to determine the dissolved oxygen content and the water temperature. Then samples were obtained using a 1/2 pint bailer. The following samples were obtained and stored in acid-rinsed polyethylene sample bottles:

a) 1/2 quart sample, filtered through a 45 um filter in the field and acidified with 2 to 3 ml of distilled concentrated nitric acid. This sample was used for trace metals species as well as calcium, sodium, magnesium, potassium and silica analyses.

b) 1 1/2 quart sample, not filtered or acidified, for use in analyses of all parameters except those listed in parts a and c.

c) 100 ml sample, preserved with H_2SO_4 at a pH less than 2 for nitrate analysis.

The pH, sulfite content, and conductance of the unfiltered and non-acidified sample were determined in the field at the time of the sampling. Samples were chilled to 4^oC and transported to UND's analysis laboratory as soon as possible, Before sampling any well the well was pumped until at least three times the volume of water standing in the well is removed.

In addition to sampling the groundwater and leachate wells, the well levels were monitored every month in the winter season and once every two weeks in the summer season.

Each sample was labeled with the following.

Name of Collector:

Name of Collection Site:

Code Number:

Date of Collection:	Time of Collection:
Amount of Acid Added:	
Filtered (yes or no):	Sulfite content: using Hack Kit
Field pH:	Field DO:
Field Temperature:	Field Conductance:

C-3. Groundwater and Leachate Analyses

The University of North Dakota tested all samples in accordance with the test parameter list given in Table C-1. Prior to disposal of the test sludge a limited number of groundwater samples were taken

Table C-1. Analytical test parameters for sludge, water, and ash related samples.

Species Sought	Method	Sludge Solids	Sludge Liquors	Water	Ash
Major:					
Calcium	AA	X	X	X	X
Iron	AA	X	X	X	X
Magnesium	AA	X	X	X	X
Sodium	AA	X	X	X	X
Silicon	AA	X	X	X	X
Carbonate	CO_2 evolution	X	X	X	X
Hydroxide	Titration	X	X	X	X
Sulfate	Titration	X	X	X	X
Sulfite	Iodimetry	X	X	X	X
Minor:					
Arsenic	AA/Hydride	X	X	X	
Barium	AA	X	X	X	
Boron	Curcumin Method	X	X	X	
Cadmium	AA	X	X	X	
Chromium	AA	X	X	X	
Cobalt	AA	X	X	X	
Lead	AA	X	X	X	
Manganese	AA	X	X	X	
Mercury	AA/vapor	X	X	X	
Potassium	AA	X	X	X	
Selenium	AA/Hydride	X	X	X	
Silver	AA	X	X	X	
Nitrate	Ion Specific Electrode		X	X	
Chloride	Ion Specific Electrode	X	X	X	
Fluoride	Ion Specific Electrode	X		X	
Miscellaneous Laboratory Tests:					
Sp. Gr.	ASTM C188				X
Fineness(+325)	ASTM C204				X
Ignition Loss	ASTM C311				X
Total Alkalinity			X	X	
Total Solids			X	X	
Total Dissolved Solids			X	X	
Total phosphorous	APHA Test No, 425F		X	?	
COD			X	X	
Miscellaneous Field Tests:					
Conductance				X	
Dissolved Oxygen				X	
PH				X	
Temperature				X	
Sulfite	Iodimetry, Hach Kit			X	

to determine the COD and coliform. For quality control, standard ERA or EPA water samples were analyzed on a monthly basis.

The methods used for the determination of these parameters are described below:

Alkalinity (carbonate)

The alkalinity is determined by titrating a 25-ml sample with standard sulfuric acid or hydrochloric acid to a pH of 4.0. A pH meter will be used to determine the end point of titration. The alkalinity is expressed a milligrams per liter calcium carbonate, but is actually a determination of the buffering capacity of the liquor owing to a number of weak acid species. The sensitivity of the method is about 1 mg/l.

Chloride (A.S.T.M. DS12-67, Method C)

Solutions of ferric ammonium sulfate and mercuric thiocyanate are added to the sample. The Chloride ion reacts with the mercuric thiocyanate to produce thiocyanate ion which in turn combin with ferric ion to form red ferric thiocyanate. The intensity of the color is proportional to the concentration of chloride and is measured spectrophotometrically.

Total Phosphorous (Test No. 425F. APHA, 14th ed, 1975)

Ammonium molybdate and potassium antimony 1 tartrate react in acid medium with phorphorous to form an antimony-phosphomolybdate complex. Adding ascorbic acid reduces the complex resulting in an intense blue color which is proportional to the phosphorous concentration. This is measured spectrophotometrically at 880nm.

Fluoride

Fluoride is analyzed using an Orion, Model 94-09 solid state electrode with a calomel single junction reference elctrode. The procedure used is essentially that of the Orion instruction manual for fluoride electrodes.

Nitrate

Direct measurement using a specific ion electrode.

Boron

(Curcumin Method, Test No- 107A, Standard Methods for the Examination of Water and Wastewater, 13th ed. 1971, APAA.AWWA.WPCF) The water sample is acidified and evaporated in the presence of curcumin. A red-colored product (rosocyanin) is formed which is proportional to the concentration of Boron. Standards and samples are read spectrophotometrically at 540nm.

Solids (total)

A clean evaporating dish is ignited at 550 ± 50°C for 1 hour in a muffle furnace. After ignition, the dish is cooled, desicated, and weighed. This gives the tared weight of the dish. Then the water sample is added to the pre-weighed dish and is evaporated to dryness on a steam bath or in a drying oven at 103-105°C. The dish is then cooled and weighed. The total solids are calculated from the tared weight and gross weight of the dish.

Solids (dissolved)

The dissolved solids method is the same as total solids method except the water sample must be first filtered through a membrane filter paper in a gooch crucible. The sensitivity of this method is 1 mg/l.

Sulfate

Indirect - Titration of excess Barium with EDTA Spectrophotometric end point detection. (Method developed by Dr. D. Tallman, NOrth Dakota State University.)

Trace Metals

Trace metal analytical procedures are given in Table C-2.

Analysis of Fly Ash Samples

A description of the procedures and for anionic analyses fly ash and related solids is given in Table C-3; a summary of results is given in Tables C-4 through C-6.

Table C-2. Methods for trace metal analysis.

Element	Method
Arsenic	Direct hydride generation, $NaBH_4$ with NaI as prereductant N_2 etraned H_2 flame wavelength - 193.7 nm EDL Source background correction used
Barium	graphite furnace* atomizetemperatur 2350°C wavelength 553.6 nm Ar and H_2 as purge gas
Cadmium	graphite furnace* atomizetemperatur 1500°C wavelength 228.8 nm background correction used method of standard additions
Calcium	flame-N_2O-C_2H_2 wavelength 422.7 nm K added as ionization suppressant
Chromium	graphite furnace* atomization temperature 2200°C wavelength 357.9 nm N_2 and H_2 as purge gas
Cobalt	graphite furnace atomization temperature 2200°C wavelength 240.7 nm
Iron	flame - air C_2 H_2 wavelength 248.3 nm
Lead	graphite furnace* atomization temperature 1800°C wavelength 217.0 nm
Magnesium	flame N_2O-C_2H_2 wavelength 285.2 nm K added as ionization suppressant
Manganese	graphite furnace* atomization temperature 1900°C wavelength 279.8 nm

Table C-2. (continued)

Mercury	cold vapor generation, with 20% $SnCl_2$ wavelength 253.7 nm
Potassium	flame air-C_3H_8 wavelength 766.5 nm
Selenium	direct hydride generation, $NaBH_4$ N_2 entraned H_2 flame wavelength 196.1 nm EDL Source background correction used
Silver	graphite furnace* atomization temperature 1800°C wavelength 328.1 nm
Sodium	flame air -C_3H_8 wavelength 330.2 nm

Notes: 1. Hollow Cathode lamp used as source unless noted

2. H_2 included as purge gas to enhance absorption.

* Varian Model CRA90

Table C-3. Analytical method for fly ash, fly ash sludge and related solid materials (anions).

Chloride ASTM D512-67 (modified)

Method C - Colorimetric. For solid samples a continuous extraction was carried out by agitation with 1N HNO_3 for two hours. Color in the extract was removed with a strongly acidic cation exchange resin (H+ form).

Fluoride ASTM D1179-72

Method B - Ion selective electrode. An acidic slurry was distilled for isolation of the Fluoride.

Carbonate ASTM D1756-62 (modified)

Gravimetric method with absorption of evolved CO_2 on Ascarite.

Sulfate

Determined as total sulfur by Leco high frequency induction furnace method with oxidizable forms of sulfur substracted.

Sulfite

Determined as oxidizable forms of sulfur by an iodimetric titration with a dead stop end point detection used when sample color prevents the use of a visual indicator.

Table C-4. Lime sludge analyses (6 samples).

Parameter		Maximum Value	Minumum Value	Mean Value	Method*	Note
Arsenic	ug/g	20.2	2.6	10.4	B	
Boron						
Cadmium	ug/g	.18	< .05	.04	B	Less than values calculated as .01
Calcium	%CaO	32.4	29.3	31.2	A	
Cobolt	ug/g	.57	.11	.38	B	
Iron	%Fe_2O_3	.60	.29	.47	A	
Magnesium	%MgO	.37	.10	.21	A	
Managanese	Mg/g	54.3	24.0	39.0	B	
Mercury	ug/g	.29	< .03	.17	B	Less than value calculated as .01
Potassium	%K_2O	.14	.02	.08	A	
Selenium	ug/g	45	2.3	3.4	B	
Silicon	%SiO_2	11.6	3.2	7.3	A	
Sodium	%Na_2O	.38	.05	.18	A	
Carbonate	%CO	6.23	.03	2.38	A	
Chloride	ug/g	36.6	13.5	20.5		
Flouride	ug/g	550	356	418		
Sulfate	%	54.0	47.7	50.3		
Sulfite	ug/g	8140	300	3270		
Insol. in. 1N HCL	%	3.0	1.0	2.2		

*A- Lithium Metaborate Fusion
B- Teflon bomb decomposition

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Table C-5. Fly ash sludge analyses (16 samples).

Parameters		Maximum Value	Minimum Value	Mean Value	Method*	Note
Arsenic						
Boron						
Cadmium	ug/g	0.72	0.22	0.48		Only six samples done.
Calcium	%CaO	17.3	13.3	15.5	A	
Cobalt	ug/g	6.00	2.01	3.67	B	Only six samples done.
Iron	$\%Fe_2O_3$	8.92	6.15	7.37	A	
Magnesium	%MgO	4.08	2.36	3.21	A	
Manganese	ug/g	477.3	443.5	464.4	B	Only six samples done.
Mercury						
Potassium	$\%K_2O$	2.33	.94	1.60	A	
Selenium	ug/g					
Silicon	$\%SiO_2$	36.1	27.4	33.6	A	
Sodium	$\%Na_2O$	3.00	1.30	2.10	A	
Carbonate	%	0.45	0.03	0.13		
Chloride	ug/g	20.6	5.9	11.2		
Flouride	ug/g					
Sulfate	%	27.0	16.1	20.8		
Sulfite	ug/g	578	9	124		
Insol. in. 1N HCl	%	35.1	25.1	30.9		

*A - Lithium Metaborate Fusion
B - Teflon bomb decomposition

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Table C-6. Dry fly ash analyses (5 samples).

Parameter		Maximum Value	Minimum Value	Mean Value	Method*
Arsenic					
Boron					
Cadmium					
Calcium	%CaO	20.2	14.9	17.1	A
Cobalt					
Iron	$\%Fe_2O_3$	9.64	8.69	9.06	A
Magnesium	%MgO	6.22	5.44	5.84	A
Manganese					
Mercury					
Potassium	$\%K_2O$	1.55	1.44	1.51	A
Selenium					
Silicon	$\%SiO_2$	58.1	52.5	55.3	A
Sodium	$\%Na_2O$	6.18	2.21	3.89	A
Carbonate	$\%CO_2$	.07	.03	.05	
Chloride	ug/g	16.9	7.8	11.5	
Flouride					
ulfate	%	10.5	7.2	9.4	
ulfite	ug/g	280	183	224	
nsol. in. 1N HCl	%	41.4	36.5	38.3	

A - Lithium Metaborate Fusion
B - Teflon bomb decomposition

APPENDIX D. PHYSICAL TESTING OF SOIL AND SLUDGE FROM CENTER, NORTH DAKOTA

D.1. Physical Testing of the Overburden at the Center, ND, Mine.

D.1.1. Sampling Procedures

Three continuous cores (thinwall tube sampler) were taken from randomly chosen sites near the sludge disposal pits. Additional cores were taken from the bottom of the sludge disposal pits 1A, 2B, 3A, 3B and 3C. These samples were also used to obtain physical properties as well as pre-disposal pore water for chemical analysis.

Five grab samples were obtained for use in the leaching column study. Again these samples were classified by physical tests. The samples were an oxidized sand, an oxidized glacial till, an oxidized brown clay, an unoxidized grey clay, and an anodized grey silt.

D.1.2. Testing Procedures

The continuous core and pit bottom core samples were visually classified. Natural moisture, liquid limit, plastic limit, specific gravity, permeability, unconfined compression, grain size distribution, and percent saturation determinations were made. In addition, classification of the overburden was performed by two systems, the Unified Soil Classification and the American Association of State Highway and Transportation Officials (AASHTO) systems. All physical tests performed were in accordance with American Society for Testing and Materials specifications for soils.

The five grab samples of overburden used in the leaching column study were tested primarily for classification purposes. Thus, only liquid limit, plastic limit, specific gravity and grain size distribution determinations were made. Natural moisture determinations were made only on the grey silt and lay samples as the others were obviously not at "field-condition" moisture contents. Classification of the materials was done in accordance with the Unified Soil Classification and AASHTO Classification systems.

D.1.3. Results of Physical Testing of Overburden

Table D-1 contains the complete set of summary data for the physical testing of one of the continuous cores of the reclaimed area immediately south of the sludge disposal pits.

The data indicates that the overburden in the reclaimed area were fine grained soils of four types:

1) A grey clay with a very noticeably grainy texture. The clay is occasionally quite dry and hard. The clay could be classified as a CL clay (inorganic, low plasticity) by the Unified Soil Classification System or as an A-6 to A-7-6 soil by the AASHTO Soil Classification System. The grey clay consisted of 2 to 29 percent sand-size particles and 71 to 98 percent fines(-.074 mm).
2) A grey clay that could be classified as a CH clay (inorganic, high plasticity) by the Unified Soil Classification System or as as an A-7-6 soil by the AASHTO Soil Classification System. The grey clay consisted of 2 to 3 percent sand size particles and 97 to 98 percent fines(-.074 mm).
3) A brown clay that could be classified as a CL clay (inorganic, low plasticity) by the Unified Soil Classification System or as an A-6 to A-7-6 soil by the AASHTO Soil Classification System. The brown clay has a grainy texture similar to the Square Butte Electric Cooperative lignite fly ash. It consisted of 9 to 30 percent sand-size particles and 70 to 91 percent fines (-.074 mm).
4) A hard grainy grey clay that could be classified as a ML/OL soil (Inorganic silts and very fine sands, silty or clayey fine sands, or clayey silts with slight plasticity or organic silts and organic silty clays of low plasticity) by the Unified Soil Classification

Table D-1. Overburden characterization of sample SC-1.

Depth Feet	Soil Description	% H_2O 110°C	% Saturation	Specific Gravity	Liquid Limit	Plastic Limit	Plasticity Index	% -200 (.074) Material
0 - 3	-	-	-	-	-	-	-	-
3 - 6	Grainy grey clay	-	-	-	-	-	-	-
6 - 9	" " "	15-16	74	2.72	35.8	21.8	14.0	90.9
9 - 12	" " "	19.2	65	2.80	-	-	-	-
12- 15	Grey, brown clay mixture	30.7	-	2.77	67.0	28.9	38.1	96.9
15- 18	" " " "	29-31	72	2.77	69.0	27.5	41.5	96.8
18- 21	Grainy grey clay	25-27	80	2.72	38.0	20.7	17.3	91.3
21- 24	" " "	23-25	82	2.72	40.0	21.3	18.7	91.9
24- 27	" " "	26.3	-		44.2	22.2	22.0	93.4
27- 30	" " "	21-22	85-91	2.72	34.9	20.2	14.7	71.2
30- 33	" " "	-	-	-	-	-	-	-
33- 36	" " "	22-25	92	2.68	43.2	19.7	23.5	93.0
36- 39	" " "	-	-	-	-	-	-	-
39- 42	Lignite	-	-	-	-	-	-	-
42- 45	"	-	-	-	-	-	-	-
45- 48	Grainy grey clay	-	-	-	-	-	-	-
48- 51	" " "	19.1	-	2.71	40.0	20.9	19.1	84.2
51- 54	Grainy grey clay (Undisturbed, sandstone-like	18-20	83-86	2.72	-	-	-	-
54- 57	"	18-19	89-95	2.72	-	-	-	-
57- 60	Grainy grey clay	18.3	80	2.75	-	-	-	-

Table D-1. (continued)

Depth, Feet	Permeability cm/sec	Classification		Unconfined Compressive strength, psf	Shear strength (cohesion), psf	Wet Density gm/cm^3
		Unified	AASHTO			
0 - 3	-	-	-	-	-	-
3 - 6	-	-	-	-	-	-
6 - 9	vertical 1.07×10^{-7}	CL	A-6	-	-	-
9 - 12	-	-	-	-	-	1.83
12- 15	-	CH	A-7-6	-	-	-
15- 18	-	CH	A-7-6	2566	1283	1.66
18- 21	-	CL	A-6	1813	907	1.80
21- 24	-	CL	A-6	1860	930	1.90
24- 27	-	CL	A-7-6	-	-	-
27- 30	vertical 8.88×10^{-7}	CL	A-6	2673	1337	2.00
30- 33	-	-	-	-	-	-
33- 36	vertical 6.4×10^{-8}	CL	A-7-6	-	-	-
36- 39	-	-	-	-	-	-
39- 42	-	-	-	-	-	-
42- 45	-	-	-	-	-	-
45- 48	-	-	-	-	-	-
48- 51	-	CL	A-6	-	-	-
51- 54	horizontal 1.54×10^{-6}	-	-	-	-	1.96
54- 57	-	-	-	9362	4681	2.07
57- 60	-	-	-	-	-	1.99

system or as an A-4 soil by the AASHTO Soil Classification system. It consisted of 10 percent of sand-size particles and 90 percent fines (-.074 mm).

Mixture of the first three overburden types occurred randomly throughout the examined cores. The three main overburden types generally had distinct boundaries between themselves. Often any one of the types occupied several thinwall sample tubes. The depth from one boundary to another varied to as much as 36 feet.

For the unconfined compression tests of the overburden material the higher strengths were attained on the drier grey & brown clays.

A number of laboratory constituent head permeability tests, as described in The Measurement of Soil Properties in the Triaxial Test, 2nd edition, 1962 pp. 139-140, by A.W. Bishop and D.J. Henkel, were performed on samples from various depths and various overburden materials. Ninety-two, Ninety and Eighty-three psi. confining, influent & effluent pressures respectively were used. Sample size was 1.5 inch diameter x 3 inches length.

Laboratory permeabilities must be viewed with some caution due to the sample being handled several times as well as the possibility of entrapped air in the soil due to high percent of fines. The latter would lower the permeability of the sample. Results should be interpreted as accurate within several hundred percent.

Tables D-2 through D-6 contains the complete set of summary data for the physical testing of the thinwall tube samples taken from 1A, 2B, 3A, 3B, & 3C prior to disposal of sludge at these sites.

The soils encountered were nearly identical to soils obtained in the continuous cores mentioned earlier.

Table D-7 contains the summary data for the physical characteristics of the five grab samples of overburden material used in the leaching column study. All tests for classification were run according to ASTM guidelines.

Table D-2. Physical testing data on thinwall tube samples from location 1A.

Disposal Site:	1A (Lime FGD sludge vee disposal)				
Section No.:	25				
Boring No.:	1 & 6	2 & 7	3 & 8	4 & 9	5 & 10
Visual Observations:					
0"-20"	Grainy grey clay	----	----	----	Grainy grey clay
20"-40"	Grainy grey clay	Grainy grey clay	Grainy grey clay and some fat grey clay deposits.	Grainy grey clay	Grainy grey clay
40"-60"	Grainy grey clay	Grainy grey clay		Grainy grey clay	Grainy grey clay Some fat clay.
60"-80"	Predominantly grainy grey hard clay. Some fat grey brown clay.	Grainy grey clay	Grainy grey to grey/black very hard clay.	Grainy grey clay	Grainy grey hard clay, occassional chunk of fat grey brown clay.
80"-100"	Grey-brown clay	Grainy grey clay	Same as 60"-80"	Grainy grey clay	Gray clay
%H_2O (110°C)/Wet Density/% Saturation: gm/cm^3					
0"-20"	----	----	----	----	----
20"-40"	24.5%	Approximately	Approximately	Approximately	24.2/1.94/87%
40"-60"	----	21% to 22%	21% to 22%	21% to 22%	20.4/2.01/86%
60"-80"	21.5%	Moisture	Moisture	Moisture	22.1/1.91/79%
80"-100"	----	----	----	----	----

Specific Gravity (Avg. of 2 trials on boring 5 (20"-40") and boring 10 (40"-60") samples): 2.76
(2.77) 2.74

Permeability, cm/sec:

Horizontal	Boring 6	20"-40" (1.9 x 10^{-8})
Vertical	Boring 5	20"-40" (2.5 x 10^{-8}), Boring 6 ( ) 3.12 x 10^{-8}

Approx. Visual Classification of Soil: CL (Unified Soil Classification System)
A-6 or A-7-6 (AASHTO Soil Classification System)

Table D-3. Physical testing data on thinwall tube samples from location 2B.

Disposal Site:	2B			
Section No:	35			
Boring No:	1	2 & 3	4 & 5	6
Visual Observations:				
0"-20"	----	Fat grey clay	Dark grey clay parts are waxy	----
20"-40"	----	Grainy grey clay	----	Grainy grey clay
40"-60"	Grainy grey clay	Grainy grey clay. Bottom portion is harder and grainier than top portion.	Grainy grey clay	Grainy grey clay
60"-80"	----	Grainy grey clay	Hard grainy grey clay	Hard grainy grey clay
%H_2O (110°C)/Wet Density/% Saturation:				
0"-20"	----	----	----	----
20"-40"	----	----	----	----
40"-60"	----	11.0/1.85/48	----	12.5/----/----
60"-80"	----	----	10.5/1.88/46.56 (may have dried out in storage)	10.0/----/----

Specific Gravity (Avg. of two trials on boring 2 40"-60" and boring 4 60"-80" samples): 2.76

Permeability, cm/sec:

Horizontal
Vertical Boring 2 40"-60" sample 1×10^{-7} Boring 4 60"-80" sample 2.7×10^{-8}

Approximate Visual Classification of Soil: CL by Unified Soil Classification System
A-6 or A-7-6 by AASHTO Soil Classification System

Table D-4. Physical testing data on thinwall tube samples from location 3A.

Disposal Site:	3A				
Section No:	36				
Boring No:	1	2	3	4	5
Visual Observations:					
0"-20"	Grainy grey clay	Grainy grey brown clay mixture.	Grey clay	Grainy grey clay	Grainy grey clay. Some brown clay and fat grey clay deposits.
20"-40"	Grainy grey clay	Same as 0"-20"	Mostly grainy grey clay. Some brown clay.	Grainy grey clay and fat grey clay	Grainy grey clay. Some fat grey clay deposits.
40"-60"	Grainy grey clay	Grainy grey clay	Grainy grey clay	Grainy grey clay	Same as 20"-40"
60"-80"	Grainy grey clay	Wet brown clay, not as grainy as above materials. Some grainy, hard grey clay.	Striated grainy grey clay	Grainy grey clay. Some fat grey clay deposits.	Grainy grey clay
80"-100"	Grainy grey clay	----	Grainy grey clay Some brown clay	Grey clay	Grey clay
%H_2O (110°C)/Wet Density/% Saturation:					
0"-20"	----	----	----	----	----
20"-40"	----	----	11.0/----/----	----	----
40"-60"	18.0/----/----	18.5/----/----	----	21.4/----/----	18.6/----/----
60"-80"	----	----	----	----	----

Specific Gravity (Avg. of two trials on boring & samples):

Permeability, cm/sec:

Horizontal (Boring sample)
Vertical (Boring sample)

Approximate Visual Classification of Soil: CL by Unified Soil Classification System
A-6 or A-6-7 by AASHTO Soil Classification System

Table D-5. Physical testing data on thinwall tube samples from location 3B.

Disposal Site:	3B			
Section No.:	36			
Boring No.:	6	7	8	9
Visual Observations:				
0"-20"	Grey clay	Grainy grey clay	Grainy grey clay	Grey clay
20"-40"	Grey clay	Grainy grey clay	Grainy grey clay	Predominantly grainy grey clay. Some 1/2"-1" lenses of brown clay, hard grainy grey clay and fat grey clay.
40"-60"	Grainy grey clay	Grainy grey clay	Grainy grey clay. Grainy hard, grey clay. Fat grey clay.	Grainy grey clay
60"-80"	Grainy grey clay	Grainy grey clay	Grainy grey clay	Mainly grey clay. Some shale and brown clay chunks.
80"-100"	Grey clay	Grey clay	Brown clay	
%H_2O (110°C)/Wet Density/% Saturation:				
0"-20"	----	----	----	----
20"-40"	14.1/----/----	----	----	17.0/----/----
40"-60"	----	----	----	----
60"-80"	----	----	----	----

Specific Gravity (Avg. of two trials on boring & samples):

Permeability, cm/sec:
Horizontal (Boring sample)
Vertical (Boring sample) By TWS 1.69×10^{-8}

Approximate Visual Classification of Soil: CL by Unified Soil Classification System
A-6 or A-7-6 by AASHTO Soil Classification System

Table D-6. Physical testing data on thinwall tube samples from location 3C.

Disposal Site: 3C

Section No.: 36

Boring No.: 10

Visual Observations:

0"-20"

20"-40"

40"-60"

60"-80"

% H_2O (110°C)/Wet Density/% Saturation:

0"-20"

20"-40"

40"-60"

60"-80"

Specific Gravity (Avg. of two trials on boring & samples):

Permeability, cm/sec:
Horizontal (Boring sample)
Vertical (Boring sample)

Approximate Visual Classification of Soil:

Table D-7. Leaching column study grab sample characteristics.

Soil Description	% H_2O (110°C)	Liquid Limit	Plastic Limit	Plasticity Index	%-200 (.074 mm) Material	D_{60}/D_{10}	Classification Unified	Classification AASHTO
1. Oxidized Sand-Brown, lots of fines	--	24.9	21.0	3.9	46	41.5	SM-SC	A-4
2. Oxidized Glacial Till-Brown, lots of fines	--	36.9	18.3	18.6	68	28.6	CL	A-6
3. Oxidized Brown Clay	--	62.6	26.9	35.7	98.6	--	CH	A-7-6
4. Unoxidized Grey Silt-Actually a grey clay	17.6	53.1	22.4	30.7	100	--	CH	A-7-6
5. Unoxidized Grey Clay	17.2	50.8	23.4	27.4	100	--	CH	A-7-6

D.2 Physical Testing of the Fly Ash FGD Sludge From the Square Butte Electric Cooperative Unit No. 2

D.2.1 Sampling Procedures

Lignite fly ash FGD sludge was sampled at random intervals by two methods:

1) directly off the vacuum filters at the Square Butte Electric Cooperative's Unit No. 2, and
2) directly from the piles of sludge at the mine disposal sites immediately following deposition by the sludge trucks.

The samples were placed in impermeable air tight containers immediately and were labelled with a number designating the date of sampling, type of sample, disposal method (i.e. pit bottom or vee type disposal), and disposal location. The samples were then returned to the University of North Dakota in Grand Forks, North Dakota, and stored at ambient temperatures for testing.

In addition to these FGD sludge samples a 50 gallon drum sample of sludge was obtained on 7/10/78 for laboratory compaction and compression testing. The drum sample was obtained from the interior of a sludge pile at disposal site #2B, section 35, 24 hours after deposition by a sludge truck in order to minimize segregation of particles, due to settling, in transit back to the laboratory. The storage drum was plastic lined and air tight.

Fly ash used as the alkalinity source for Unit No. 2's scrubber was sampled on a regular schedule by Minnkota Power Company personnel and sent back to the University of North Dakota in metal containers for testing. In addition, Minnkota Power Company personnel sampled FGD sludge from the vacuum filters on a regular basis and conducted percent solids tests on the samples. Thickener underflow pH tests were performed on corresponding samples.

Since the effects of laboratory remolding on the engineering properties of the FGD sludge were unknown, it was decided to obtain 8 sludge samples from the field site for permeability and triaxial compression testing. The samples were obtained from sludge pit #2B in section 35. They were taken from a sludge pile on 8/5/78, 24 hours after deposition by a sludge truck. The method used in sampling was to push 1.37-1.39 inch inside diameter plastic thin-walled tubes and samples were removed from the sludge pile along with a large block of the surrounding sludge, placed in air tight plastic containers, and transported back to UND for testing.

D.2.2 Testing Results of FGD Sludge

All tests were run in accordance with guidelines established by ASTM. But the Atterberg limits testing, which includes the "Plastic Limit", "Liquid Limit", and "Plasticity Index", were very difficult to perform on the lignite fly ash FGD sludge. Due to the thixotropic nature of the sludge it would be classified as non plastic. We could not roll the sludge to an 1/8 inch. diameter thread at any moisture content (ASTM D424). The liquid limit tests (ASTM D423) are of questionable value in this case. Again because of the sludge's thixotropic nature the sludge would not stick to the brass cup at any moisture. Instead of flowing as a liquid, it would slide. A detailed record of the liquid limit will be given in the final report.

Vacuum Saturation testing, a simulation of freezing and thawing durability, ASTM C593, apparently shows that the fly ash FGD sludge has no resistance to freezing and thawing. Upon soaking sample in water it completely dissolved very rapidly. A less severe test consisting of alternately freezing and thawing the same samples as in ASTM C593, for five cycles. Following the freeze-thaw cycles the specimens were in good condition and their compressive strengths were 67 psi as compared to 32 psi when compacted at 1-2% above optimum moisture.

Results of the testing are shown in Tables D-8 and D9.

Table D-8. Lignite fly ash sludge characteristics.

1)	% Solids 60°C Drying	75
2)	% H_2O 60°C Drying	
	a) Total Wt. Basis	25
	b) Dry Wt. Basis	33
3)	pH of Thickener Underflow	4-8
4)	pH of Pore water	7.5-9
5)	Specific Gravity	2.5
6)	% Fines (-.074 mm) Particles	74-92
	% Coarse (+.074 mm) Particles	8-26
	% Silt-sized (.002-.074 mm) Particles	74-92
	% Clay-sized (<.002 mm) Particles	0
7)	Liquid Limit (based on dry wt.)	26
8)	Plastic Limit	Non-Plastic
9)	Plasticity Index	0
10)	Classification	
	a) Unified Soil Classification System	ML/OL
	b) AASHTO Soil Classification System	A-4
11)	Std. Proctor Compaction	
	a) Optimum Moisture	22-23%
	b) Maximum Dry Density	90 pfc
12)	Pozzolanic Bonding After Deposition	Yes
13)	Unconfined Compressive Strength	32-46 psi
14)	Triaxial Compression	
	a) Field Deposition Conditions	
	Cohesion	13 psi
	Angle of Internal Friction	35°
	b) Maximum Density Conditions	
	Cohesion	0-20 psi (Varies $\bar{w}$ curing time)
	Angle of Internal Friction	41° - 46°

Table D-8. (continued)

15) Freeze Thaw Durability	None
16) Permeability	
a) Field Deposition Conditions	$6x10^{-6}$ cm/sec
b) Maximum Density Conditions	$2x10^{-6}$ cm/sec
17) Compressability	Study not complete

Table D-9. Compressive strength of 4" diameter std. Proctor specimens (lignite fly ash FGD sludge 07108SSB0935).

Length of Curing Period	Failure stress, psi
1 - Day (6 Samples)	11.9 - 31.4 (Avg. 15.7)
3 - Day (1 Sample)	27.1
7 - Day (2 Samples)	31.9 Avg.
14 - Day (1 Sample)	27.9
28 - Day (1 Sample)	33.8
7 - Months (5 Samples)	53.3 Avg.
9 1/2 Months (4 Samples)	38.2 - 59.0 (Avg. 47.4)

Appendix E.

POTENTIAL EFFECTS ON GROUNDWATER OF FLY ASH AND FGD WASTE DISPOSAL IN LIGNITE SURFACE MINE PITS IN NORTH DAKOTA

by

Gerald H. Groenewold,[1] John A. Cherry,[2]
Oscar E. Manz,[3] Harvey A. Gullicks,[4]
David J. Hassett,[3] and Bernd W. Rehm[3]

1. North Dakota Geological Survey, Grand Forks, N.D.
2. University of Waterloo, Waterloo, Ontario
3. University of North Dakota, Grand Forks, N.D.
4. Soil Testing Services of Minnesota, Minneapolis, Minn.

ABSTRACT

Increased reliance upon coal-burning power plants is resulting in the generation of large quantities of waste products. Fly ash and flue-gas-desulfurization (FGD) waste constitute the two major by-products of coal-buring power plants in the U.S. and at mine-mouth power stations a common method of disposal of these wastes operations is by emplacement in surface mine pits.

In this study, initially funded by EPA and presently by DOE, the potential impacts of surface mine pit disposal of fly ash and FGD waste at the Center Mine near Center, North Dakota, are being evaluated. The FGD waste at the Center site is generated by using the highly-alkaline fly ash as the SO_2 sorbent. The research involves field studies, laboratory studies, and computational geochemical studies to determine the potential for FGD waste and fly ash to affect groundwater quality.

FGD waste from North Dakota lignite, when placed in contact with water in various types of laboratory experiments, produces leach fluids with high SO_4, Mg and Na concentrations and pH values in the range of 7.0 to 8.5. Toxic metal and non-metal concentrations are generally not significantly in excess of drinking water standards. The concentrations of SO_4 and Ca are limited by the solubility of gypsum in conjunction with the degree of ion pairing between the major cations and sulfate. Highest total dissolved solids occur when Na and Mg are present as soluble salts.

In contrast, North Dakota lignite fly ash produces leach water that is potentially toxic because it has a pH commonly between 11 and 13 and contains concentrations of As and Se which exceed Primary Drinking Water Standards by a maximum factor of 12 and 80, respectively. Analyses of groundwater samples from piezometers in unmined areas, in spoil with no buried waste and in spoil with waste have provided confirmation of the expectations of

groundwater quality degradation based on the laboratory experiments. Piezometers in and very near zones of buried fly ash yielded severely contaminated waters with high-pH and high concentrations of As, Se and Mo, whereas water from piezometers in spoil with FGD waste contained high SO_4 and cation concentrations but showed no significant quality deterioration due to As, Se, Mo or other toxic metals. Groundwater influenced by FGD waste is similar to groundwater in some areas of spoil without waste, where SO_4 and total dissolved solids concentrations are high. At present the areal extent of groundwater contaminated by FGD waste or fly ash at the Center site is small, but will increase gradually as a result of groundwater flow and as a result of continued waste disposal.

Environmentally safe disposal of fly ash and FGD waste in surface mine pits will require careful site selection and selective placement of wastes and the various overburden materials.

INTRODUCTION

Increased use of coal for production of electricity is resulting in the generation of large volumes of solid wastes, mainly in the form of fly ash as a residue from coal burning and flue-gas-desulfurization (FGD) waste as a residue from control systems for atmospheric emissions. Placement of the wastes in mine pits prior to backfilling the pits with overburden is a common method for disposal of these wastes at power plants located adjacent to surface coal mines. Although this waste disposal practice has existed for many years, little is known about the effects of fly ash and FGD waste in mine pits upon the quality of groundwater in and adjacent to the disposal areas.

This paper presents a summary of the results obtained to date from an on-going investigation of the effects of these wastes on groundwater quality at the Center Mine, operated by Baukol-Noonan, Inc., near the town of Center in western North Dakota (Figure E-1).The waste is generated by the Square Butte Electric Cooperative Milton R. Young Station. This is a mine mouth power plant that fires low sulfur lignite coal from the Center Mine. Unit #2, a 450 MW cyclone-fired boiler, is fitted with an SO_2 scrubber which utilizes the high alkalinity of the plant's fly ash as the SO_2 sorbent. It is anticipated that this type of scrubber system will see wide application in the future. Thus, this site offers an excellent opportunity to evaluate the effects of the resultant waste products on groundwater quality.

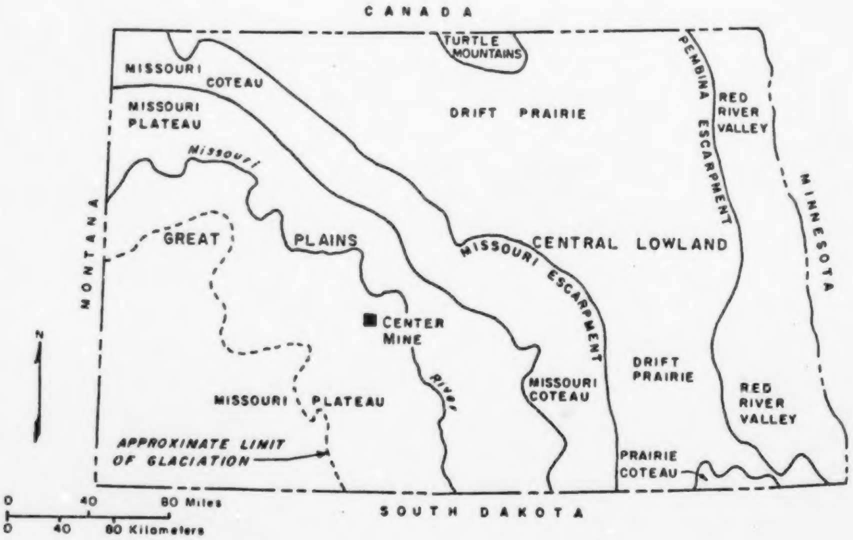
CANADA
TURTLE MOUNTAINS
MISSOURI COTEAU
MISSOURI PLATEAU
DRIFT PRAIRIE
PEMBINA ESCARPMENT
RED RIVER VALLEY
Missouri
MINNESOTA
MONTANA
GREAT PLAINS
MISSOURI ESCARPMENT
CENTRAL LOWLAND
CENTER MINE
River
N
MISSOURI COTEAU
DRIFT PRAIRIE
RED RIVER VALLEY
MISSOURI PLATEAU
APPROXIMATE LIMIT OF GLACIATION
PRAIRIE COTEAU
0 40 80 Miles
0 40 80 Kilometers
SOUTH DAKOTA

Figure E-1. Location of Center, North Dakota study area.

The investigation was initially funded by EPA and is presently funded by DOE. Although the work pertains specifically to the wastes and their effects on groundwater at the Center mine, the results have relevance to the problems of fly ash and FGD waste disposal at other mines in the lignite and sub-bituminous coal region of the Northern Great Plains.

The investigation is comprised of laboratory experiments, field monitoring of groundwater in and near areas where fly ash and FGD waste have been buried, and hydrogeochemical computations to determine the influence of solubility constraints on the chemical evolution of groundwater affected by the wastes.

In the early part of the study, emphasis was placed only on determining the chemical composition of the FGD waste produced at the Center site and on determining the capability of this waste to cause degradation of groundwater quality. Later it became apparent that a considerable quantity of fly ash was being produced as a result of periods of inoperation of the flue-gas scrubber system. The fly ash, like the FGD waste, is disposed of by burial in the mine pits prior to backfilling with spoil. Although power plants equipped with fly ash scrubber systems will utilize much of the available fly ash, considerable quantities will remain requiring disposal. In addition, even with improved engineering, it is expected that periods of scrubber-system inoperation will always occur to some extent and thus fly ash is expected to continue to be a significant waste product. Thus, the influence of fly ash on groundwater became the second major aspect of this study. Most power plants in the United States have scrubber systems that use lime or limestone rather than fly ash as the SO_2 sorbent. Therefore these plants yield large quantities of fly ash as well as FGD waste products.

The hydrogeochemical properties of fly ash and fly-ash-type FGD waste are very different and these two waste forms can have quite different effects on groundwater quality. One of the purposes of this investigation is to determine if conversion of fly ash to FGD waste offers significant potential to reduce adverse effects on groundwater. Another reason for interest in fly ash is that large volumes of this product have already been disposed of by in-pit burial at older power plants where scrubber systems have not been installed or were not installed until recently.

DESCRIPTION OF THE FIELD SITE

The Center study area (Figure E-2) is located on an upland divide bounded on the north and northeast by Square Butte Creek Valley and on the south by Hagel Creek Valley. Figure Figure E-2 shows the field study area, waste disposal site (active mining area), location of groundwater instrumentation in unmined areas adjacent to the disposal sites, and the location of the hydrostratigraphic cross section shown in Figure E-3.

The climate in the Center area is semi-arid. The topography of the area is rolling. Glacial sediment (till) veneers much of the study area. The Tertiary coal-bearing strata consists of sand, silty sand, and lignite aquifers separated by silty and clayey materials (Figure E-3).Glaciofluvial sand and gravel are present in the Square Butte Creek Valley.

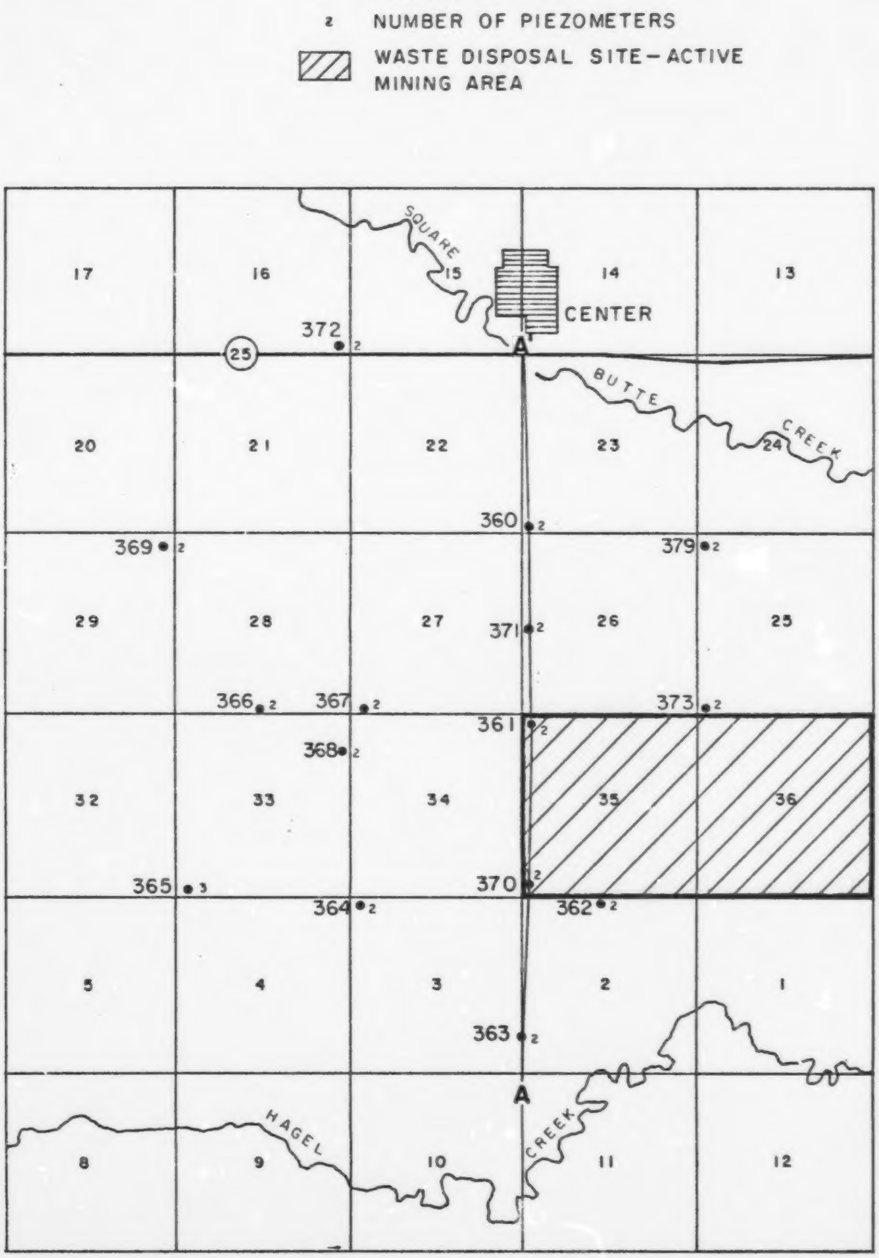
● PIEZOMETER SITE
2 NUMBER OF PIEZOMETERS
▨ WASTE DISPOSAL SITE—ACTIVE MINING AREA
SQUARE
BUTTE
CREEK
HAGEL
CREEK
CENTER
25
A'
A
17
16
15
14
13
20
21
22
23
24
29
28
27
26
25
32
33
34
35
36
5
4
3
2
1
8
9
10
11
12
372 2
360 2
369 2
379 2
371 2
366 2
367 2
373 2
361 2
368 2
365 3
364 2
370 2
362 2
363 2

Figure E-2. Location of detailed study site, groundwater instrumentation in areas adjacent to study site, and location of cross section A-A' (Figure E-3).

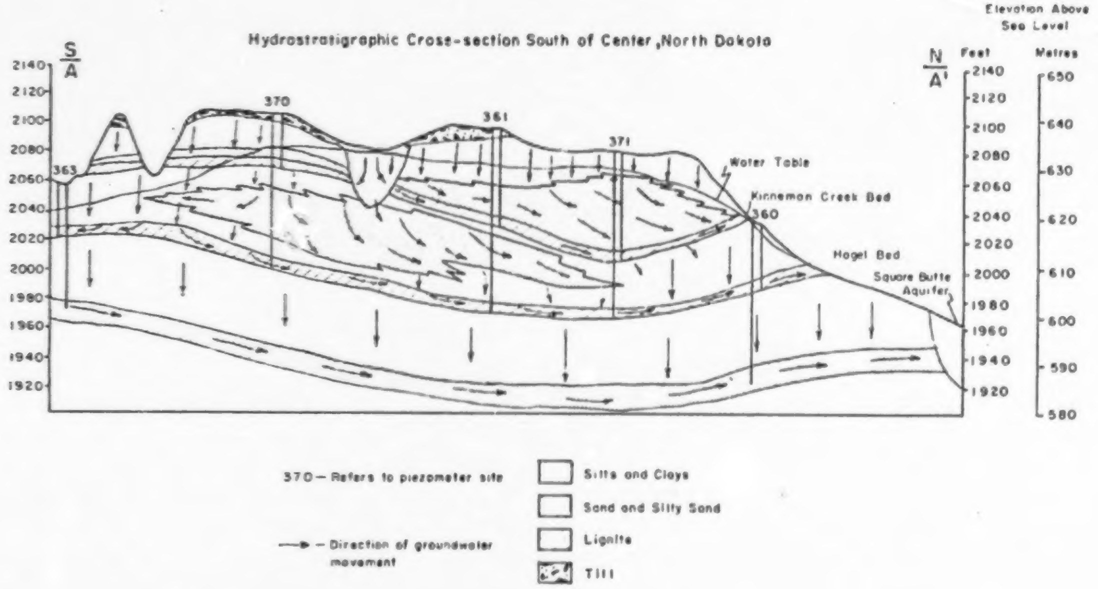
Hydrostratigraphic Cross-section South of Center, North Dakota
S
A
N
A'
Elevation Above Sea Level
Feet
Metres
2140
2120
2100
2080
2060
2040
2020
2000
1980
1960
1940
1920
650
640
630
620
610
600
590
580
363
370
361
371
360
Water Table
Kinneman Creek Bed
Hagel Bed
Square Butte Aquifer
370 — Refers to piezometer site
— Direction of groundwater movement
Silts and Clays
Sand and Silty Sand
Lignite
Till

Figure E-3. Hydrostratigraphic cross section of the Center area. See Figure E-2 for location of cross section.

The shallow stratigraphic units of hydrologic interest in unmined areas include two lignites; the Kinneman Creek Bed and the Hagel Bed, and a clayey sand unit which underlies the Hagel Bed (Figure E-3). The Kinneman Creek and Hagel lignite beds are both mined at the present time. Much of the interval between the lignites consists of sandy materials as does part of the body of materials overlying the Kinneman Creek Bed.

The hydraulic interaction between the various stratigraphic units is shown in Figure E-3. As is typical of most proposed and active surface mining areas in the Northern Great Plains, the Center site generally lies within an area of groundwater recharge. Therefore, waste products emplaced in the near-surface portion of the landscape lie in the path of infiltrating water and can potentially have a severe impact on groundwater quality.

Nearly all recharge to the groundwater system occurs during spring runoff and occasionally during periods of relatively heavy precipitation in the fall. Recharge occurs, to some degree, over most of the landscape but is concentrated in restricted positions. These include areas of standing surface water and ephemeral stream bottoms. In most other landscape positions, the majority of the precipitation is lost through either runoff or the process of evapotranspiration (Moran et al., 1978,[1] Groenewold et al., 1979[2]).

In general, the movement of groundwater in the fine-textured materials (aquitards) is vertical and downward. Movement of groundwater in the sand and lignite aquifers is essentially horizontal or lateral (Figure E-3). Very

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slow downward movement of groundwater through the various aquitards supplies water to the aquifers. The aquifers, in turn, lose water by downward seepage to underlying aquitards and transmit water laterally to discharge areas along slopes, or, as in the case of the clayey sand unit, to glaciofluvial valley-fill materials (Figure E-3).

The hydrologic units of major interest in the waste disposal area include the spoil materials and unmined units below the base of the spoils. FGD waste disposal was initially intended for two distinct positions within the mined area. These positions were the base of the mine pit and the V-notch between spoil ridges (Figure E-4).However, due to numerous breakdowns in the scrubber system during the initial part of the study, nearly all of the FGD waste generated was emplaced in V-notch areas. Fly ash disposal was totally restricted to V-notch positions.

Typically, these two landscape positions are significantly different from the standpoint of groundwater considerations. The base of the mined area is relatively permeable and is generally below the postmining water table. The V-notch between spoil ridges is typically 10 to 20 metres above the base of the spoils and thus commonly above the position of the postmining water table. A major objective of the continuation of this study under DOE funds is a more detailed evaluation of the effect of FGD waste disposal in a saturated pit bottom area.

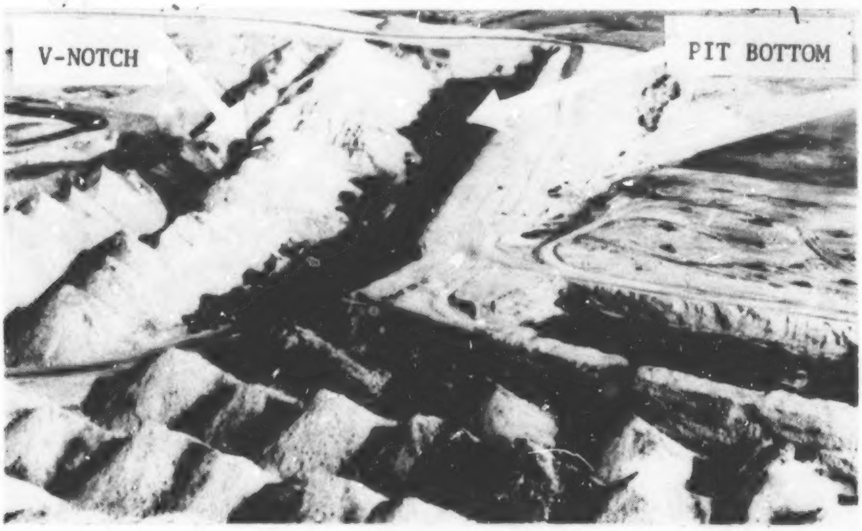

Figure E-4. Photograph of Center Mine showing typical V-notch and pit-bottom disposal areas.

PHYSICAL PROPERTIES OF FLY ASH AND FGD WASTE

Each truckload of waste from the Milton R. Young Station consists of about two tonnes of slag and 18 to 22 tonnes of FGD waste. As received from the vacuum filter and subsequent to drying at 60°C, the solids content is 75%. The FGD waste is classified as silt (A-4) according to the AASH classification, and ML/OL by the Unified Soil Classification System. According to ASTM D-698, the maximum dry density is 90 pcf (1.44 gm/cm^3) and optimum moisture 22.5%. Permeability of field samples of FGD waste, as determined in the laboratory, is 6 X 10^{-6} cm/sec and under maximum density conditions is 2 x 10^{-6} cm/sec. A truckload of FGD waste and slag covers an area of approximately 14 feet x 14 feet (18.0 m^2) and is 5 feet (1.5 m) high in the middle. Initially the waste is very soft. However, after a few days of exposure, it will hold the weight of an adult person.

A truckload of FGD waste left exposed since January 1979 has shown very little change in surface appearance during the subsequent 16 months. It is possible to break off pieces of this material by hand and easily indent the surface. In the laboratory, a chunk of this exposed waste slaked in a few minutes when immersed in water. The dry density after 16 months exposure was 1.1 gm/cm^3 and the unconfined compressive strength was 116 psi or 8.1 Kg/cm^2. This is indicative of long term pozzolanic activity since the maximum unconfined compressive strength of moist cured cylinders compacted to ASTM D-698 (4 inch (10.16 cm) diameter cylinder, 4.5 inches (11.4 cm) deep, compacted with 5½ lb (2.49 kg) hammer, dropping 12 inches (30.48 cm), 25 blows per layer for 3 layers) only averaged 47.4 psi (3.3 kg/cm^2) after 9½ months.

During field sampling operations in October, 1979, it was found that driving 3 inch (7.62 cm) diameter thin-walled tubes through the buried FGD waste in a V-notch disposal area required much less effort than driving through the mine spoil below. In some parts of the V-notch as well as the pit bottom disposal areas, two or three layers of FGD waste have been emplaced. Since the rubber-tired dozers and trucks were prone to sink into the waste, even after several weeks of exposure, a 1 to 2-ft (30 to 60 cm) layer of mine spoil was required on top of each layer before driving on the waste.

The presence of about two tonnes of non-porous, coarse, glassy slag with each 18 to 22 tonnes of FGD waste causes porous channels and pockets for easy movement of water through the waste. The FGD waste also commonly shows extensive cracking after short periods of exposure in disposal areas. Where the sludge has been deposited only one truckload deep, numerous closed depressions between adjacent truckloads act as catchment basins and allow for the accumulation of water during heavy precipitation.

When the scrubber is not in operation the fly ash is diverted into a 2½-ft (76.2 cm) diameter x 8-ft (2.4 m) long rotary drum mixer inclined at 15°C. A shaft with blades attached uniformly mixes in about 15% water prior to dumping into the same trucks used for hauling FGD waste. In contrast to the FGD waste, the rubber-tired dozers are able to drive on the fly ash almost immediately without sinking in. After a few weeks of exposure, it is possible to break off pieces of the fly ash by hand and indent the surface, similar to the FGD waste that had been exposed for 16 months. However, even though the compressive strength of the fly ash is only 39 psi (2.7 kg/cm^2), there was only slight slaking when specimens were immersed in water.

In order to prevent slaking, the fly ash must have some degree of compaction, with at least 15% water, and be allowed to cure for about a week. In the laboratory, a series of compaction tests were performed at different compactive efforts and varying moisture contents. Even when compacted at optimum moisture content of about 15%, according to ASTM D-698, the test specimen that was immersed in water within an hour after compaction was completely slaked within a few minutes. However, similar specimens that were cured in sealed containers at room temperature for over a week and then immersed in water, experienced no slaking whatsoever. In addition, unusually high compressive strengths in the order of 2759 psi (193 kg/cm^2), were attained with this short curing period. Other specimens compacted at lower compactive efforts produced much lower compressive strengths. Specimens compacted to approximately the same density as the field sample (1.4 gm/cm^3) had compressive strength equal to 136 psi (9.6 kg/cm^2), and showed no signs of slaking.

Laboratory specimens of fly ash compacted to ASTM D-698 have permeabilities in the order of 2×10^{-7} cm/sec. However, from observations in the field it is evident that the field compacted fly ash is much more pervious and has numerous channels, pockets, and cracks. In contrast to the FGD waste, the fly ash displays very little slaking, provided the compacted fly ash-water mass has had several days of curing previous to being subjected to precipitation or infiltrating groundwater. If dry fly ash is simply dumped into a container or pool of water it will not set up or harden while immersed.

WASTE COMPOSITION

Fly Ash

Fly ash is the residue that remains after coal is burned for steam generation. It is a direct result of the occurrence of non-combustible inorganic impurities in the coal. The elemental composition of fly ash produced at the Milton R. Young power plant at the Center mine and, for comparison, the composition of fly ash produced by several other power plants in the Northern Great Plains region are shown in Table E-1. The fly ash is comprised of numerous chemical compounds, the most abundant of which are silica (SiO_2) as glass, silica as quartz, $CaSO_4$ (anhydrite), Fe_2O_3 (hematite), Fe_3O_4, CaO, MgO, and C (carbon) The elemental composition of the fly ash produced at the Center site is generally similar to the compositions of fly ash generated by lignite-burning power plants elsewhere in the Great Plains region (Table E-1). The composition differs significantly from that of fly ash produced from hard bituminous coal. The bituminous-coal fly ash has a higher silica (SiO_2) content, a higher iron content, and lower contents of calcium, magnesium and sulfur.

It should be noted that although elemental compositions of fly ash and FGD waste provide a useful means for comparison of these wastes, they do not indicate how the wastes will influence the chemical composition of water brought into contact with the wastes. In this regard we draw attention to the fact that mineralogical analyses of fly ash conducted in this investigation and those reported in the literature indicate that most of the sodium, Table E-1. Composition of fly ash produced by several power plants in the U.S.

Laboratory No.	Type of coal source for each fly ash	Chemical analysis (percent)								
		SiO_2	Al_2O_3	Fe_2O_3	S+A+F	Free CaO	Total CaO	MgO	SO_2	Alkalies as Na_2O
M 6498	Bituminous blend	46.1	19.0	18.6	83.7	2.2	8.2	1.3	1.6	0.72
M 6510	Lignite	37.1	11.8	7.3	56.3	0.5	21.8	5.6	2.6	4.23
M 6514	Lignite	37.2	15.5	5.6	58.3	0.2	24.3	11.3	0.9	0.07
M 6535	Subbituminous	28.8	20.0	4.1	53.0	2.1	32.0	6.4	3.8	0.68
M 6569	Subbituminous	51.8	27.2	2.0	81.0	1.9	10.7	2.1	0.7	0.85
M 6577	Lignite	31.1	17.1	7.9	56.1	0	25.3	8.1	3.3	1.35

Laboratory No.	Mineralogical analysis (percent) estimated [1]									
	CaO	Fe_2O_3	Fe_3O_4	Fe as Fe_2O_3	Quartz	MgO	Carbon	$CaSO_4$	Glass	Misc.
M 6498	4	4	4	8	4.0	1.5	4	2.5	68	10
M 6510	4	5	5	10	4.0	-	5	-	68	10
M 6514	5	2.5	2.5	5	4.0	2.5	2.5	2.5	68	10
M 6535	4	2.5	2.5	5	5.0	1.5	1.5	4.0	70	10
M 6569	4	2.5	2.5	5	2.5	4	4	2.5	70	10
M 6577	5	5	5	10	2.5	5	5	4.0	63	10

Laboratory No.	Composition of glass in ashes (percent)								
	CaO	Al_2O_3	Fe_2O_3	SiO_2	MgO	SO_3	Alkalies as Na_2O	Total	CaO/SiO_2
M 6498	4	19	11	42	0	0	0.72	77	0.10
M 6510	18	12	(-3)	33	6	-	4.23	73	0.55
M 6514	19	16	0.6	33	9	(-0.5)	0.07	78	0.58
M 6535	28	20	(-0.9)	24	5	1.4	0.68	78	1.17
M 6569	7	27	(-3)	49	(-2)	(-0.8)	0.86	84	0.14
M 6577	20	17	(-2)	29	3	0.9	1.35	71	0.70

[1] Estimated by X-ray diffraction and optical methods

M 6498	Chicago Fly Ash (Blend)
M 6510 (1973)	Basin Electric Power Corp., Stanton, North Dakota
M 6514 (1973)	Montana Dakota Utilities, Sidney, Montana
M 6535 (1974)	Public Service Co. of Colorado, Pueblo, Colorado
M 6569 (1974)	Navajo Generating Plant, Page, Arizona
M 6577 (1974)	Minnkota Power Co., Center, North Dakota

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calcium, and magnesium in lignite fly ash is incorporated in glass and therefore is unavailable for dissolution in water. The forms of these elements that are significant with respect to the generation of total dissolved solids in groundwater are those occurring as oxides such as CaO and MgO and as sulfate salts such as $CaSO_4 \cdot 2H_2O$. Chloride salts occur in only very small concentrations in the lignite of the Northern Great Plains region and therefore these salts do not occur in the fly ash in significant amounts. The elemental composition of fly ash and FGD waste from the Milton R. Young plant is listed in Table E-2. These data indicate that fly ash from the Milton R. Young plant contains measurable concentrations of numerous heavy metals, transition metals, and toxic non-metals such as arsenic. The fly ash also contains other constituents in significant concentrations that may cause degradation of groundwater quality.

FGD Waste

FGD waste is produced using fly ash to react with sulfur dioxide in the flue gas stream from the power-generation units. The fly ash, which is very alkaline, serves as a substitute for lime or limestone in the wet scrubber system for neutralization of sulfuric acid as sulfur is removed from the flue gas. Table E-2 indicates that the composition of the FGD waste differs from that of the fly ash mainly by its high content of sulfate acquired from the flue gas. Another difference in the composition of the FGD waste and the fly ash, and one that is not evident from the elemental analyses, is the oxide content which is appreciable in the fly ash but which is very small in the FGD waste. Much of the calcium that exists as CaO in the fly ash occurs as anhydrite ($CaSO_4$) in the FGD waste.

FGD waste is composed primarily of quartz, glass, anhydrite, and iron oxides. Compounds of carbonate, fluoride, and chloride are present in only very small concentrations. Table E-2 indicates that concentrations of heavy metals and toxic non-metals such as arsenic, selenium, and fluoride present in the FGD waste are similar to those present in the fly ash.

Calcium sulfate can occur in two forms, as gypsum, $CaSO_4 \cdot 2H_2O$, and as a nonhydrated salt, $CaSO_4$, known as anhydrite. At temperatures below about 40°C at atmospheric pressure, gypsum is the thermodynamically stable compound. Anhydrite can exist, however, for long periods of time in a metastable state. Although the sulfate in the FGD waste is present primarily as anhydrite, a minor amount of gypsum probably also occurs.

Table E-2 indicates that FGD waste produced at the Milton R. Young power plant at Center is somewhat variable in composition. This variability reflects the minor variations in the composition of the coal fed to the power plant. For reasons discussed below, this variability in FGD waste composition does not appear to be significant in terms of the influence of FGD waste on groundwater quality.

HYDROCHEMICAL LABORATORY INVESTIGATIONS

The influence of FGD waste on water chemistry was studied in the laboratory by analysis of or compilation of existing analyses of (i) supernatant

Table E-2. Chemical composition of fly ash and fly ash FGD waste from the Milton R. Young Plant, Center, North Dakota.

		mg/g									µg/g					
		Ca*	Mg*	Na*	K*	CO_3	Cl	SO_4	F	SO_3	Si*	Fe*	Cd	Hg	Se	As
Fly Ash	$\bar{x}$	122.1	35.2	28.8	12.5	0.5	0.01	93.4	0.2	0.2	258.3	63380	1.13	0.29	17.2	79.6
	s	14.7	2.0	10.9	0.3	0.1	0.00	12.7	0.4	0.04	10.6	2689	0.4	0.15	3.0	18.4
	n	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Fly Ash FGD Waste	$\bar{x}$	104.8	19.0	15.0	13.6	3.2	0.01	195.6	0.3	0.1	166.3	50329	0.47	0.34	10.5	130.2
	s	24.8	3.0	4.7	4.3	8.1	0.00	57.5	0.06	0.1	39.8	6501	0.19	0.14	3.9	56.0
	n	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17

* Calculated from % oxide

liquid from FGD waste storage vessels, (ii) samples of pore water extracted from FGD waste by squeezing, (iii) samples obtained from batch elutriation tests, and (iv) samples of effluent from column experiments. The first three types of analyses represent static (no flow) conditions, whereas the column experiments were designed to determine the changes in water chemistry that occur when waters of various initial compositions flow through samples of waste.

Process Liquors and Supernatant Solutions

Table E-3 presents the results of an analysis of a sample of liquor collected from the absorber tower of the flue-gas desulfurization system at the Milton R. Young power plant and an analysis of a sample of supernatant liquid that occurred in a large vessel in which FGD waste from this power plant was transported from the field site to a laboratory. Although both samples are sulfate-salt solutions, the absorber liquid had a sulfate concentration of 65,500 mg/L whereas the supernatant liquid had a concentration of 5,130 mg/L. In each sample sodium was the most abundant cation, but it should be noted that the concentrations of calcium and magnesium were not determined.

The large difference in sulfate concentrations suggests that most of the sulfate in solution in the absorber tower precipitates from the system. For reasons described below, sulfate in water in contact with FGD waste that is discharged from the power plant does not rise to the levels measured in the absorber liquor. Providing that time for adjustment to chemical equilibrium is available, sulfate concentrations are limited by the solubility of gypsum in the presence of large concentrations of sodium and magnesium as well as calcium.

Pore Water From Squeeze Extraction

The FGD waste discharged from the power plant and transported to the mine pits contains pore water with dissolved solids. This water and the solid-phase composition of the waste represent the initial conditions of the water-and-FGD waste mass that is placed in the mine pits. To determine the chemical composition of this pore water, samples of FGD waste from field disposal sites at the Center Mine were collected on numerous occasions in 1978 and 1979. Pore water from the field samples of FGD waste was removed by squeezing, using a standard soil consolidation apparatus. For comparison, pore water from FGD waste used in leaching columns was also obtained by squeezing. The extraction method is described by Gullicks (1979[5]). The mean concentration of sulfate in the pore waters of the field samples was 10,763 mg/L with a range of 2,473 to 19,038 mg/L (Table E-4). As is evident from Table E-4, the dissolved constituents in the pore water of the field samples were at similar concentrations to those present in pore water squeezed from FGD waste used in leaching columns. The dominant cations were sodium, magnesium, and calcium. As was the case for the absorber tower liquor and the supernatant liquid, the pore waters were sulfate salt solutions. The pH of the pore water samples ranged from 7.5 to 8.9 with a mean of 8.23.

With the exception of sulfate, cadmium, fluoride, and lead, none of the mean values for the constituents included in the analyses exceeded the limits

Table E-3. Analyses of absorber tower liquor and FGD scrubber waste supernatant liquid from the Milton R. Young Plant.

ABSORBER TOWER LIQUOR[1]		FGD SCRUBBER WASTE SUPERNATANT LIQUID[2]	
Constituent	Concentration (mg/L)	Constituent	Concentration (ppm)
Aluminum	329	Bicarb. Alkalinity	0
Arsenic	0.42	Carb. Alkalinity	396
Barium	0.16	Chloride	74
Beryllium	0.015	Nitrate	8
Cadmium	0.27	Sulfate	5,130
Calcium	530	T.D.S	18,576
Cobalt	12.1	Hardness	9,160
Chromium	0.16	pH	8.9
Copper	0.4	Antimony	4.0
Iron	808	Arsenic	.0304
Gallium	0.22	Barium	.50
Lithium	2.5	Boron	290
Magnesium	9060	Cadmium	.08
Manganese	63.4	Calcium	--
Nickel	5.4	Chromium (T)	<.05
Potassium	1010	Chromium (+6)	<.05
Silicon	293	Cobalt	.60
Sodium	6760	Copper	.06
Strontium	31.4	Cyanide	.05
Uranium	2.7	Fluoride	15
Vanadium	0.34	Iron (T)	.16
Zinc	21.4	Lead	.30
		Magnesium	--
Chloride	200	Manganese	.19
Fluoride	0.55	Mercury	.00125
Sulfate	65500	Molybdenum	3.1
Sulfite	165	Nickel	.27
		Potassium	200
		Selenium	.088
		Silver	.04
		Sodium	1000
		Zinc	.04

1. Data from Twin City Testing and Engineering Laboratory, Inc., 1976[3]

2. Data from Ness et al., 1978[4]

specified in the National Primary Drinking Water Standards. The recommended limit for sulfate in drinking water is 250 mg/L. In contrast, the sulfate concentrations in the pore-water samples are larger by a factor of 10 to 76. The mean value for lead is only slightly above the maximum permissible concentration specified in the drinking water standards. Fluoride concentrations in the pore waters ranged from 1 to 28 mg/L. In contrast, the maximum permissible limit specified for fluoride in drinking water is 2.4 mg/L in

Table E 4. Comparison of the concentrations of chemical constituents in the leaching column FGD waste porewater to the concentrations found in the porewater of field samples.

Constituent	Porewater From 27 Samples of FGD Waste From Field Disposal Sites			Leaching Column FGD waste Porewater
	Range	Mean	Std. Deviation	
Arsenic, μg/L		Not Available		11.7
Cadmium, μg/L	1-156	18.6	38.7	547.0
Calcium, mg/L	298-530	423.2	53.0	395.0
Chromium, μg/L	11-63	32.1	14.8	26.9
Cobalt, μg/L	10-162	61.2	42.8	98.4
Lead, μg/L	17-219	88.0	55.8	58.0
Magnesium, mg/L	368-2903	1,633.2	802.1	2,310.
Mercury, μg/L		Not Available		0.7
Potassium, mg/L	7-354	44.3	105.5	332.0
Selenium, μg/L		Not Available		25.9
Sodium, mg/L	237-3320	1,623	1,054.7	3,200.
Total Alkalinity (as $CaCo_3$), mg/L	38-528	217.9	120.2	87.5
Chloride, mg/L	5-106	40.1	27.8	29.7
Fluoride, mg/L	1-28	13.7	7.1	5.0
Total Dissolved Solids, mg/L	4032-30,968*	17,064*	7,145*	28,273.
Sulfate, mg/L	2473-19,038	10,763	4,029	17,106.
pH	7.5-8.9*	8.23*	0.37*	8.10

* Based on 24 FGD waste porewater sample analyses

regions with a mean annual temperature of 12°C. The limit varies slightly based on the regional temperature which is taken as an index of drinking water comsumption. Cadmium concentrations in the pore waters from the field samples ranged from 1 to 156 μg/L. The mean cadmium concentration was 18.6 μg/L. The maximum permissible limit specified for cadmium is 10 μg/L. The cadmium concentration in pore water from the leaching column FGD waste was 547 μg/L.

Water from Elutriation Tests

A number of shaker-type elutriation tests were performed on FGD waste from the Milton R. Young plant. These tests were performed as part of a multi-laboratory test program designed to determine the reliability of three methods for hazardous waste evaluation. Results of the FGD waste elutriation tests are shown in Table E-5.Of the constituents included in the analyses, none exceeded the limits specified in the National Primary Drinking Water Standards.

Similar shaker-type elutriation tests were performed on samples of fly ash from the Milton R. Young Plant. Results of these tests are shown in Table E-6. Comparison of the data in Table E-6 with those in Table E-5 indicates significant differences in pH as well as arsenic and selenium concentrations. The pH from fly ash elutriation tests ranged as high as 11.46 compared to a high of 6.58 for FGD waste. Arsenic concentrations from fly ash elutriations range from 35.6 to 127 μg/L as compared to <2 μg/L for FGD waste. The maximum permissible limit specified to arsenic in drinking water is 50 μg/L. Selenium concentrations from fly ash elutriations range from 17.6 to 368 μg/L as compared to <2 μg/L for FGD waste. The maximum permissible limit specified for selenium in drinking water is 10 μg/L.

The concentrations of all other constituents analyzed were very similar for the fly ash and FGD waste elutriations. As discussed previously, the concentrations of all constituents in fly ash and FGD waste from the Milton R. Young plant, with the exception of SO_4, are very similar (Table E-2). Thus, the relatively high concentrations of arsenic and selenium generated by elutriation of fly ash are particularly significant and suggest selective mobilization of these constituents from the fly ash.

Table E-5. Results of a shaker-type elutriation test of FGD waste from the Square Butte Electric Cooperative Unit No. 2[1].

Parameter	Concentration in the Elutriate (Range of 3 Elutriation Methods Used
pH	4.99-6.58
Calcium mg/L	401-600
Chromium mg/L	.001-.016
Arsenic μg/L	<2
Barium mg/L	.225-.716
Cadmium μg/L	.5-2.7
Lead μg/L	<1.5-12.1
Mercury μg/L	<.3
Selenium μg/L	<2
Silver mg/L	.002-.024

[1] Performed by David J. Hassett, Chief Chemist, Engineering Experiment Station, University of North Dakota, April, 1979, as part of a multi-laboratory test program designed to test the effectiveness and reliability of three elutriation methods for hazardous waste evaluations.

Table E-6. Results of a shaker-type elutriation test of a lignite fly ash from the Square Butte Electric Cooperative Unit No. 2[1].

Parameter	Concentration in the Elutriate (Range of 3 Elutriation Methods Used)
pH	6.96-11.46
Calcium mg/L	394-951
Chromium mg/L	.031-.160
Arsenic µg/L	34.6-127.0
Barium mg/L	.757-1.069
Cadmium µg/L	1.3-17.6
Lead µg/L	2.7-22.4
Mercury µg/L	<.3-0.4
Selenium µg/L	17.6-368.0
Silver mg/L	.007-.015

[1] Performed by David J. Hassett, Chief Chemist, Engineering Experiment Station, University of North Dakota, April, 1979, as part of a multi-laboratory test program designed to test the effectiveness and reliability of three elutriation methods for hazardous waste evaluations.

A simple experiment was devised to determine the potential mobility of arsenic from fly ash from the Milton R. Young plant. Ten samples of fly ash, collected from the plant on a monthly basis, were elutriated with distilled-deionized water. The results of this experiment appear in Table E-7. The pH of the 10 resultant fluids ranges from 11.95 to 12.75. The arsenic concentrations ranged from 15 to 770 µg/L, suggesting that release of arsenic from fly ash from the Milton R. Young plant may constitute a significant concern.

Effluent from Leaching Columns

Leaching column experiments were conducted utilizing FGC waste from the Milton R. Young plant. Column experiments were not performed using fly ash. The flow-through leaching experiments were performed by packing 10 cm-long columns of FGD waste in translucent plexiglass tubes that were 1.5 cm in diameter. Each tube was fitted with machined plexiglass base plates with a rubber o-ring and an effluent discharge opening and a Teflon stopcork. An inert porous plastic filter pad was placed on the base plate to support the sample and retard passage of particulate matter from the column. The mass of FGD waste placed in each tube was compacted to achieve a wet density of approximately 1.7 g/cm^3, which was the wet density determined for FGD waste samples under field conditions.

The FGD waste used in the columns was compared to seventeen FGD waste samples from two disposal areas at the Center site and was found to have no

Table E-7. Arsenic concentrations and pH of fluids produced by elutriation of fly ash samples.

Sample	pH	Arsenic (μg/L)
FA 1 (8/10/78)	12.75	33.0
FA 2 (9/11/78)	12.02	164.0
FA 3 (10/30/78)	12.06	217.0
FA 4 (11/15/78)	12.11	79.0
FA 5 (12/ 8/78)	12.28	15.0
FA 6 (1/31/79)	12.05	212.0
FA 7 (2/ 9/79)	11.95	770.0
FA 8 (3/ 8/79)	12.28	433.0
FA 9 (4/11/79)	12.21	70.0
FA 10 (5/ 1/79)	12.03	15.0

1. Each fly ash sample was weighed into a polycarbonate centrifuge tube, about 6.3 g of ash in each tube.
2. 25 ml of distilled deionized water were added to each tube.
3. The tubes were gently agitated with inversion for 24 hours ± 0.5 hours.
4. Contents of the tubes were centrifuged and the clear upper layer was analyzed.

significant differences in chemical composition. Fourteen columns were used, each with a different type of leaching fluid as follows: distilled-deionized water, groundwater from the Hagel lignite bed (the main lignite aquifer at the Center site), groundwater from the base of the spoil in one of the mined segments at Center, water from the effluent weir of the bottom-ash settling tank at the Milton R. Young plant, and ten waters obtained by elutriation of samples of five different types of overburden from the Center site with distilled-deionized water and groundwater from the Hagel lignite bed. Prior to passage of the various influent liquors through the columns, a filtered (0.45 μm) sample of each was analyzed for total dissolved solids, pH, potassium, sodium, magnesium, calcium, chloride, sulfate, alkalinity, fluoride, cobalt, cadmium, chromium, and lead.

The ten elutriation fluids were produced by stirring a mixture of one part overburden material with four parts water. After 16 to 20 hours of stirring, the mixture was allowed to settle and the liquid was removed by decantation. The decanted liquid was then added to fresh overburden material in the same proportions indicated above and was shaken in a wrist-action shaker until measurements of pH, electrical conductance, sodium, and total dissolved solids were found to indicate a stable condition. Before the fluids were used in the columns, they were passed through 2 μ filter paper.

The results of chemical analyses of the elutriation fluids and of the other fluids used in the column experiments are listed on Table E-8. Of the

Table E-8. Analyses of influent liquors for leaching column experiments.

Analyses of the ten types of elutriation fluids produced for use as leaching column influent liquors.

Type of Leaching Column Influent Liquor:	Hagel Lignite Bed Groundwater Elutriated With					Distilled-Deionized Water Elutriated with				
	Oxid. Sand	Oxid. Glacial Till	Oxid. Brown Clay	Unox. Grey Clay	Unox. Silt	Oxid. Sand	Oxid. Glacial Till	Oxid. Brown Clay	Unox. Grey Clay	Unox. Silt
Elutriations:	2	3	3	2	2	2	4	3	2	2
Constituent										
Cadmium, µg/L	<1	<1	<1	<1	<1	<1	1.4	<1	<1	2.1
Calcium, mg/L	11.0	364.	212.	17.0	8.4	28.7	403.	191.6	13.2	4.36
Lead, µg/L	7.1	8.4	3.1	9.4	12.8	0.8	15.7	9.2	14.6	19.0
Magnesium, mg/L	33.2	260.9	163.4	16.4	13.4	12.0	271.5	126.8	5.59	4.17
Potassium, mg/L	7.4	11.2	20.8	22.8	18.0	1.4	9.2	14.0	11.2	11.2
Sodium, mg/L	248.	420.	264.	296.	304.	36.	240.	76.	156.	134.
Total Alkalinity, as ppm $CaCO_3$	227.4	175.5	222.3	376.6	399.8	43.7	38.6	57.1	197.6	153.3
Chloride, mg/L	8.9	21.1	9.9	7.6	8.9	3.2	16.2	3.9	2.1	3.4
Fluoride, mg/L	0.7	0.8	0.8	1.0	0.8	0.8	1.1	0.7	1.3	1.0
Total Dissolved Solids, mg/L	1016.	4135.	2599.	1078.	1121.	186.	4248.	1943.	381.	563.
Sulfate, mg/L	408.	2417.	1070.	331.	401.	172.	2645.	891.	146.	121.4
pH	8.7	8.5	8.6	8.8	8.7	9.0	8.5	8.3	8.7	8.7

Table E-8. (continued)

Analyses of leaching column influent liquors other than those produced by the elutriation of overburden materials

Constituent	Distilled Deionized Water	Hagel Lignite Bed Groundwater	Groundwater From the Base of the Spoil Piles	Water From the Effluent Weir of the Bottom Ash Settling Tank
Cadmium, μg/L	<1	<1	<1	<1
Calcium, mg/L	6.7	11.0	138.4	137.
Lead, μg/L	0.6	2.3	6.1	6.5
Magnesium, mg/L	0.5	6.8	150.1	66.2
Potassium, mg/L	0	4.6	20.8	26.4
Sodium, mg/L	0	384.	176.	360.
Total Alkalinity, as ppm $CaCO_3$	4.1	747.6	277.8	64.3
Chloride, mg/L	<0.1	3.8	5.9	9.3
Fluoride, mg/L	<0.1	1.3	<.1	0.8
Total Dissolved Solids, mg/L	24.	1,147.	1,947.	2,011.
Sulfate, mg/L	2.0	122.	1,056.	1,090.
pH	5.7	8.4	8.1	8.2

five types of overburden materials used to obtain elutriation fluids, two (the glacial till and the oxidized brown clay) produced solutions that contained high concentrations of total dissolved solids and sulfate. These high concentrations occurred for both types of elutriation solutions, the groundwater from the Hagel lignite bed and distilled-deionized water. These results suggest that some of the types of overburden in the Center area are capable of causing poor quality groundwater to occur in spoil where fly ash or FGD waste are absent. Field evidence in support of this conclusion is presented in a following section of this paper.

The other three types of overburden used to obtain the elutriation fluids yielded solutions with total dissolved solids between 1016 and 1121 mg/L when groundwater from the Hagel lignite bed was used for elutriation and values between 186 and 563 mg/L when distilled-deionized water was used (Table E-8). The total dissolved solids of groundwater from the Hagel lignite bed used for elutriation was 1147 mg/L. Although the elutriation fluids had similar values of total dissolved solids as the Hagel lignite bed groundwater, they had more than twice the sulfate concentrations and half or less than half the alkalinity of the groundwater from the Hagel Bed.

All influent liquors were added to the columns until an overflow level was attained. The columns were filled daily to the overflow level, after recording the fluid level decline of the previous day. For most columns, effluent representing the first seven pore volumnes, the eleventh through seventeenth pore volumes, and the forty-fourth through fiftieth pore volumes were chemically analyzed. For some of the columns, experimental problems necessitated that other pore volume samples be analyzed.

The results of a typical leaching column experiment are shown in Figure E-5. The column experiments indicated that the concentrations of sodium and sulfate increased to approximately the same high levels in the initial pore volumes of all the columns, regardless of influent chemistry. However, by 50 pore volumes, the sodium concentrations generally decreased to approximately the concentrations of the influent. The sulfate concentrations by 50 pore volumes were generally slightly higher than influent concentrations. The magnesium concentrations always increased to approximately the same levels in the first few pore volumes, regardless of influent chemistry. However, by 20 pore volumes the magnesium concentration typically decreased to approximately that of the influent. The calcium concentrations in all the columns attained approximately the same levels in the first few pore volumes, regardless of influent chemistry. The calcium concentration typically showed a slow decrease from 10 to 50 pore volumes. In contrast to the other ions, the calcium concentrations at 50 pore volumes were typically 2 to 10 times greater than the influent concentrations for calcium.

These data indicate that the FGD waste contains soluble compounds of magnesium, sodium, and sulfate. These soluble salts are generally flushed from the columns by 10 pore volumes. Calcium concentrations increase to a maximum from pore volumes 1 to 10. Thereafter, the effluent becomes saturated with respect to gypsum. Once the magnesium and sodium compounds are flushed, only gypsum dissolution contributes to the column effluent.

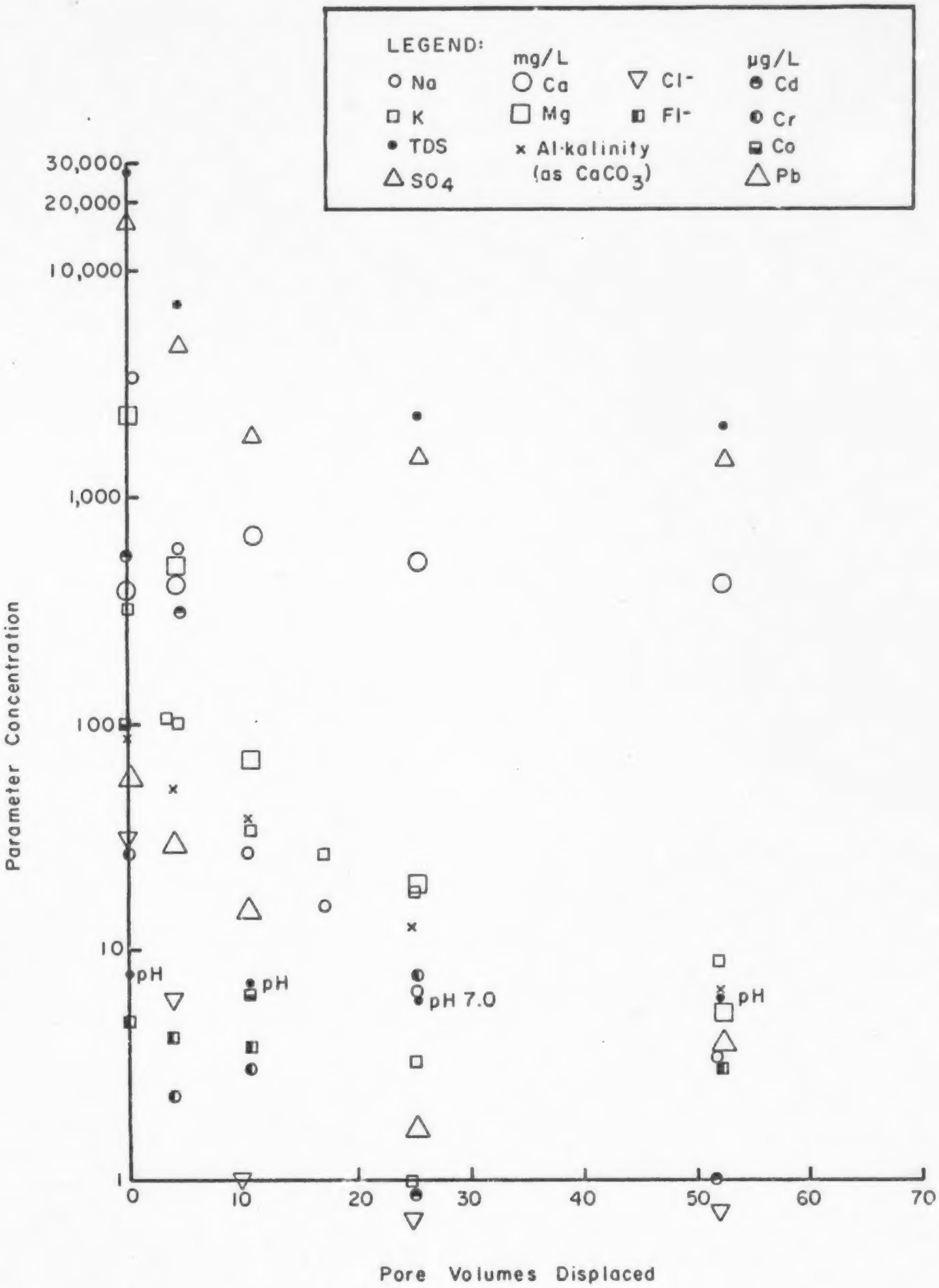

Figure E-5. Analytical parameters of column A011 versus average pore volume displacement.

HYDROGEOCHEMICAL PROCESSES

The results of a representative group of the chemical analyses of pore water squeezed from FGD waste, FGD waste column effluent, and contaminated and unaffected spoil groundwater were processed using a computer program known as WATEGM for equilibrium geochemical computations. With the analytical results as input, this program computes the distribution of chemical species and determines saturation indices for selected solid phases. The thermodynamic basis for a program similar to WATEGM is described by Truesdell and Jones (1974[6]). Documentation and explanation of WATEGM is currently being prepared as part of a PhD thesis by Carl D. Palmer, University of Waterloo, Waterloo, Ontario. Representative WATEGM results are listed in Table E-9 which shows that a characteristic feature of water in contact with FGD waste and fly ash is that it is at or very near equilibrium with respect to gypsum ($CaSO_4 \cdot 2H_2O$). Although the solid-phase form of the calcium sulfate in the FGD waste and fly ash is anhydrite ($CaSO_4$), the equilibrium control on calcium sulfate in solution is gypsum, because gypsum is the thermodynamically stable phase at temperatures below about 40°C.

Although the waters are in equilibrium with respect to gypsum, there is considerable variability in the concentrations of sulfate and calcium in the various solutions (Figure E-5). This variability is attributed to the presence of relatively large concentrations of sodium and/or magnesium. These cations form pairs or complexes with sulfate, such as $MgSO_4^o$, $NaSO_4^-$, and $Na_2SO_4^o$, which greatly increase the solubility of gypsum because a large percentage of the total dissolved sulfate exists in these solution species (Table E-9). Sulfate is the main component of total dissolved solids of water in contact with FGD waste and fly ash. Because equilibrium sulfate concentrations can vary considerably as a result of differences in sodium and magnesium in the water, there is considerable variation in the total dissolved solids of waters in contact with FGD waste and fly ash.

Sulfate salts of sodium and magnesium, such as thenardite (Na_2SO_4), mirabilite ($Na_2SO_4 \cdot 10H_2O$), and epsomite ($MgSO_4 \cdot 7H_2O$) are extremely soluble in water. The concentrations of these two cations in pore water squeezed from FGD waste, FGD waste column effluent, and groundwater influenced by fly ash burial are much below their sulfate-salt solubility limits (Table E-9). The concentrations are probably limited by the amounts of sodium and magnesium in soluble solid phases in the FGD waste or fly ash which, for reasons presented below, are much less than total amounts of these elements in the wastes. Figure E-5 indicates that as water was passed through the columns of FGD waste, the concentrations of sodium and magnesium rapidly declined to levels much below those for the initial pore volumes. This is particularly the case for magnesium, which for many of the columns generally decreased to concentrations of less than 100 mg/L and in a few cases less than 20 mg/L from initial values generally greater than 2000 mg/L. Mass balance calculations for the column effluent indicate that although the concentrations are much lower than the initial values after 50 pore volumes were passed through the columns, less than 20% of the total mass of these elements within the FGD waste was removed. This indicates that most of these elements in the columns exists within relatively insoluble solid phases such as the glass component of the FGD waste. In this context, elemental analyses of FGD waste are of only limited value for use in

Table E-9. Representative results of WATEGM chemical equilibrium program utilizing various waters as input.

	pH	Ca	Mg	Na	K	Alka[2]	SO_4	TDS	SI[3]	SI	SI	SI	SI	%[4]	%	%
		<-------			mg/L			------->	CALC	GYP	THEN	MIRA	EPSO	$CaSO_4^o$	$MgSO_4^o$	$NaSO_4^- + Na_2SO_4^o$
Initial effluent from FGD waste leached by spoil groundwater (P.V. 1-7)	8.5	384	515	800	130	172	5134	7927	+1.22	-0.6	-4.94	-4.14	-2.13	10	25	<1
Final effluent from FGD waste leached by spoil groundwater (P.V. 44-50)	7.6	413	163	250	28	328	2073	3800	+0.84	-0.12	-6.15	-5.35	-2.73	20	5	<1
Average of six samples of interstitial pore water squeezed from FGD waste	8.41	366	1172	2904	62	189	11672	21569	+0.72	-0.02	-3.75	-3.40	-1.74	4	24	7
Average of 2 piezometers near fly ash disposal sites[1]	7.38	378	218	3112	178	467	6811	9690	+0.25	-0.07	-3.90	-3.53	-2.47			
Average of 15 piezometers in spoils	6.75	284	153	325	19	670	1522	3400	-0.05	-0.30	-5.98	-5.71	-2.78			

[1] C-136 and C-139 (see Table E-12).

[2] Alkalinity expressed as mg/L of $CaCO_3$.

[3] SI = log $(IAP \cdot K_{eq}^{-1})$ from WATEGM.

[4] % of total SO_4 (data for columns represent an average of three effluents).

estimating the contaminant yield capability because most of the total mass of each element is present in a relatively insoluble form.

Standard methods for determining the mineralogical composition of solids, such as x-ray diffraction and optical microscopic examination, are also only of limited use because these methods generally provide inadequate information on solid-phase components that are present as small percentages of the total volume of sample.

Although Figure E-5 shows that effluent concentrations of calcium and sulfate decline with an increase in the cumulative number of pore volumes passed through the columns, this does not imply that disequilibrium exists with respect to gypsum. Computed saturation indices for gypsum indicate that the effluent is at or very near equilibrium with respect to gypsum throughout the entire period of effluent discharge (Table E-9). The changing concentrations of calcium and sulfate at equilibrium are caused by the changes in concentrations of sodium and magnesium that are controlled by the rate at which these elements are released from the FGD waste to the flowing water. As less and less sodium and magnesium are released to the pore water, less sulfate exists in the form of sodium and magnesium ion pairs or complexes and therefore solubility of gypsum decreases.

Although important in the flowing column effluent, ion pairing and complexing is probably even more significant in the nonflowing squeezed porewater. Under nonflowing conditions the porewater can be expected to take on a higher concentration of sodium and magnesium sulfate salts than under the flowing conditions present in the columns. This will allow for greater gypsum dissolution and sulfate generation than under flowing conditions, as indicated by the very high equilibrium concentrations of sulfate in porewater squeezed from FGD waste (Table E-9).

Mass balance calculations indicate that after passage of 50 pore volumes through the columns, less than 25% of the total sulfur had been removed from the columns. Based on the assumption that all of the sulfur represented in the elemental analysis of the FGD waste exists as calcium sulfate (anhydrite), it can be concluded that hundreds of pore volumes would have to be passed through the FGD waste in order to remove all of the available sulfate. After the soluble sulfate is removed, the waste will contribute only very low levels of dissolved solids to water in contact with the waste. A small fraction of the total sulfate in FGD waste or fly ash probably occurs as sodium or magnesium sulfate salts. Because these salts are very soluble, they would be quickly removed by flowing water. There appears to be no significant source of sulfate in FGD waste or fly ash other than sulfate salts.

EFFECTS ON GROUNDWATER AT THE CENTER SITE

Piezometers and Sampling Methods

Approximately one hundred and fifty piezometers have been installed within the waste-disposal area and unmined areas adjacent to the Center Mine (Figure E-2). The piezometers were screened at various stratigraphic positions in both areas. The purpose of this instrumentation was two-fold: first, to gather baseline data on the occurrence, flow, and chemistry of groundwater in unmined and spoils settings; second, to evaluate the effects of FGD waste and fly ash on groundwater quality in disposal areas.

All piezometer test holes were drilled utilizing a rotary drilling rig. With few exceptions, the piezometer test holes were drilled using only air for circulation, thereby eliminating potential chemical contamination associated with the injection of fluids during drilling operations.

All piezometers consist of 5-cm-diameter PVC pipe with a 1.5 metre preslotted PVC screen. Washed sand was packed around the screened interval. Grout was then emplaced from the top of the sand pack to the surface. All piezometers were bailed at least twice prior to sampling. Sampling of the piezometers followed EPA recommendations. A more detailed discussion of well installation and sampling procedures can be found in Groenewold et al. (1979[2]). Water levels in all the piezometers were monitored on a monthly basis. These data were used to develop an interpretation of groundwater flow in the study area. In addition, single-well-response tests of selected piezometers were conducted to determine the hydraulic conductivities of the various units.

Groundwater Occurrence and Flow

As previously discussed, groundwater conditions in the Center area are typical of most active and proposed surface mining areas in the Northern Great Plains. A detailed discussion of hydrogeologic conditions in the Center area can be found in Groenewold et al. (1979[2]). The hydrologic regime is primarily a function of climate, stratigraphy, and topography. Most precipitation is lost through evapotranspiration. Recharge to the groundwater system occurs during spring runoff and occasionally during high intensity precipitation events.

Once infiltrating water moves below the rooting zone, the rates and directions of flow are largely determined by the lithology of the sediments (Figure 3). Movement of water through sand and lignite aquifers is generally lateral whereas movement through fine-textured Tertiary sediment and glacial till is generally vertical and downward (Moran et al., 1978[1], 1978a[7]).

The hydraulic conductivity of Tertiary sand commonly ranges from 10^{-5} to 10^{-6} m/sec; lignite generally ranges from 10^{-5} to 10^{-7} m/sec; fine-textured Tertiary sediments and glacial till range from 10^{-8} to 10^{-10} m/sec (Groenewold et al., 1979[2], Rehm et al., 1980[8]).

Groundwater of suitable quality for domestic use is not readily available in most areas of the Northern Great Plains. In western North Dakota, 60 to 70 percent of the small-yield domestic wells withdraw groundwater from lignite aquifers. The permeability of the lignite is largely due to fracturing, apparently a function of unloading. Thus, although as many as 10 or more lignites are present in many areas, typically only the near surface lignites are sufficiently fractured to constitute aquifers.

The near-surface lignites are presently proposed for extensive mining. Therefore, in many areas unmined lignite will be essentially in direct hydraulic contact with the basal portion of adjacent spoils areas. Thus the quality of water in spoils can potentially have a significant impact on groundwater in adjacent unmined areas. In addition, slow downward migration of waters from areas of spoils can be expected to affect the quality of groundwater in underlying units.

The basal portion of the spoils is often characterized by concentrations of blocky materials, particularly in the areas between spoils ridges (Winczewski, 1977[9]). This observation is substantiated by Van Voast et al., 1978[10]) who have determined that the basal portions of spoils at Colstrip and Decker Mines in Montana are characterized by greater average hydraulic conductivities than in other positions within the spoils. Their research also indicates that the mine spoils at Decker and Colstrip sites presently are at least as conductive of groundwater as the coal beds.

The movement of subsurface waters and permeability characteristics in the base of spoils areas in western North America have been addressed by various researchers (Alberta Environment, 1980[11], Davis and Rechard, 1977[12], Groenewold and Bailey, 1979[13], Groenewold and Rehm, 1980[14], Rahn, 1976[15], and Van Voast et al., 1978[10]). Hydraulic conductivity data from the basal portion of spoils in these areas show a wide range of values. Slug test values from spoils in Montana, Wyoming, and North Dakota range from 10^{-5} to 10^{-9} m/sec. Such a range of values seems reasonable given the high degree of structural, morphological, and textural variability within a given body of spoils.

Single-well-response tests were run on five piezometers screened in the base of the spoils at the Center mine. These data are presented in Table E-10. The data indicate considerable variability in the hydraulic characteristics in the base of the spoils. Hydraulic conductivity values range from 10^{-6} m/sec, which is similar to lignite aquifers, to 10^{-9} m/sec, which is within the range of the fine-textured sediments.

Table E-10. Hydraulic conductivity data for base of spoils--Center Mine.

Piezometer No.	Hydraulic Conductivity (m/s)
C 9	1.4×10^{-9}
C10	5.9×10^{-6}
C16	2.8×10^{-9}
C17	5.0×10^{-7}
C23	3.1×10^{-6}

Groundwater instrumentation in the mined area indicates that the basal portion of spoils is saturated over most of the study site. Potentiometric head values in most of the piezometers in the spoils have shown a fairly consistent rise over the period of the study, suggesting that equilibrium conditions have yet to be established in the spoils. Potentiometric head data suggest that groundwater recharge is occurring through the spoils. This is verified by tritium and oxygen-18 data obtained from 22 piezometers in the spoils area. The oxygen-18 data indicate that the water in the base of the spoils has not been subjected to significant evaporation as would be expected if recharge were due to the lateral movement of water from the adjacent mine pit. The tritium data indicate that the water in the base of the spoils is enriched in tritium relative to groundwater in laterally adjacent and underlying undisturbed units, indicating vertical movement and recharge of this water through the spoils.

Groundwater Composition in Unmined Areas and in Spoils Without Waste

Chemical analyses of groundwater from undisturbed units and spoils at the Center Mine are shown in Table E-11. Although considerable variability in water chemistry is apparent between the various undisturbed units, all contain water that is generically very similar. The major ions in solution in all the undisturbed units are sodium, calcium, bicarbonate, and sulfate. The Kinneman Creek and Hagel lignite beds contain Na, Ca-HCO_3, SO_4 to SO_4, HCO_3 type water. Total-dissolved solids concentrations in the Kinneman Creek and Hagel beds range from 843 to 1631 mg/L and 649 to 3874 mg/L, respectively. The nonlignitic sediments underlying the Hagel lignite bed or spoils are characterized by Na to Na, Ca-HCO_3, SO_4 to SO_4, HCO_3 type water. Total-dissolved-solids concentrations in these units range from 416 to 5051 mg/L.

Sulfate concentrations in the undisturbed units commonly exceed the recommended limit for drinking water of 250 mg/L by a factor of 2 to 4. The concentrations of iron and manganese in the undisturbed units vary considerably. Iron ranges from 20 to 1300 μg/L. The majority of the samples exceed the recommended limit of 300 μg/L. Manganese concentrations range from 60 to 2750 μg/L, all in excess of the recommended limit of 50 μg/L. Cadmium levels are generally well below the maximum permissible concentration of 10 μg/L. Lead is typically well below the maximum permissible concentration of 50 μg/L. Selenium and arsenic are below the maximum permissible levels of 10 μg/L and 50 μg/L, respectively, in all samples.

The data presented in Table E-11 indicate that the water in the base of the spoils is generally more highly mineralized, with respect to major ions, than groundwater in undisturbed units. Total-dissolved-solids concentrations in spoils at the Center Mine range from 1599 to 5338 mg/L. Sulfate concentrations range from 565 to 2520 mg/L. Concentrations of iron and manganese in spoils show a moderate increase over concentrations of these ions in undisturbed units. However, cadmium, lead, arsenic, and selenium in groundwater in spoils are within the same ranges of concentrations as in undisturbed units. All are well below the maximum permissible concentrations for drinking water.

Groundwater Composition in Waste Disposal Areas

Analyses of groundwater from piezometers in FGD waste and fly ash disposal areas at the Center Mine are shown in Table E-12. Location of the screened interval relative to buried waste is noted for each piezometer.

FGD Waste. The FGD waste had been in place for approximately 12 months prior to sampling of the piezometers. At that time three piezometers, C94,

Table E-11. Chemical analyses of groundwater from spoils and undisturbed units, Center Mine, Center, North Dakota

	Field Temp °C	Field pH	Field Cond µmhos/cm	DO	TDS	Total Hardness	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	NO_3	F
				←							mg/L					→
	SPOILS															
$\bar{x}$	9.7	6.7	3880.0	0.8	3375.6	---	348.0	232.4	361.0	15.6	1165.4	---	1454.9	8.1	0.6	0.1
s	4.2	0.3	1243.2	0.4	910.7	---	97.5	90.1	255.1	8.9	413.1	---	536.7	4.6	0.4	0.1
n	21	21	21	15	16	---	16	16	16	16	18	---	18	18	13	15
high	16.5	7.7	8000	3.5	5338.0	---	519.0	431.2	1118.0	34.0	2113.0	---	2520.0	21.0	1.8	0.3
low	2.0	6.3	1830	0.2	1599.0	---	190.0	103.5	89.5	7.5	363.6	---	565.8	2.3	0.1	0.0
	KINNEMAN CREEK BED															
$\bar{x}$	10.4	6.7	1655.6	0.4	1229.3	404.3	84.3	51.9	249.7	18.8	651.1	1.1	372.2	8.1	1.8	0.1
s	2.8	4.6	437.1	0.2	333.3	227.0	47.0	20.3	122.7	11.3	208.7	0.4	137.5	8.0	2.6	0.0
n	9	9	9	5	9	4	9	9	9	9	9	3	9	9	8	6
high	16.0	7.5	2200	0.7	1631.0	731.0	165.0	94.4	441.0	48.0	1021.1	1.4	642.7	21.0	6.5	0.1
low	6.5	6.0	975	0.2	838.0	221.0	29.0	29.0	115.0	11.4	334.3	2.6	232.6	0.5	0.1	0.05
	HAGEL BED															
$\bar{x}$	9.5	7.1	2264.3	0.4	1774.0	94.6	105.3	74.3	297.4	10.7	681.4	8.0	668.3	7.0	1.3	0.1
s	2.9	0.5	1041.8	0.5	1056.3	---	116.7	72.3	202.3	5.5	218.5	9.0	604.8	6.3	2.4	0.2
n	20	20	20	13	19	1	17	17	17	17	18	2	19	19	14	14
high	14.5	8.0	3750	1.9	3874.0	---	337.0	202.0	810.0	23.2	1098.0	14.3	2087.0	28.0	8.5	0.7
low	3.0	6.4	900	0.1	649.0	---	8.0	2.1	72.4	4.2	412.2	1.6	41.2	0.5	0.0	0.0
	SAND 5m BELOW HAGEL BED															
$\bar{x}$	9.2	7.4	3453.8	0.6	2644.8	---	153.2	80.4	567.7	10.2	835.0	---	1217.0	6.3	0.6	0.4
s	2.0	0.9	932.4	0.5	985.0	---	136.1	74.8	247.6	2.2	327.7	---	663.3	3.3	1.0	0.5
n	13	13	13	13	10	---	13	13	13	13	13	---	13	13	13	13
high	12.0	9.3	4400	1.6	4428.0	---	431.8	260.0	880.2	14.0	1288.2	---	2539.0	11.0	2.9	1.4
low	5.5	6.4	1900	0.0	1413.0	---	30.9	12.7	5.9	.74	106.8	---	415.0	2.0	0.0	0.0
	SILT 15m BELOW HAGEL BED															
$\bar{x}$	8.7	7.6	2946.5	0.5	1983.2	78.6	53.6	35.7	636.5	10.5	1154.7	12.8	694.7	11.1	2.2	0.7
s	2.6	0.5	1345.0	0.5	911.0	40.2	52.0	41.9	252.1	6.8	413.6	0.3	658.0	15.6	8.7	0.7
n	47	47	47	35	44	4	47	47	47	47	47	2	47	47	41	38
high	14.0	8.4	8000	2.7	5056.0	128.0	191.5	186.0	1311.0	36.4	1942.2	13.0	1642.6	107.2	55.8	2.3
low	3.0	5.9	600	0.1	416.0	43.3	3.5	2.8	106.5	3.5	248.0	12.6	140.9	0.5	0.0	0.0

Table E-11. (continued)

	SO_3	B	Alk.	Fe	Mn	Cd	Hg	Se	As	Pb	Ba	Cr	Co
		mg/L						µg/L					
SPOILS													
$\bar{x}$	3.8	1.0	954.7	555.6	1951.2	1.9	0.3	1.6	3.7	4.9	92.8	7.3	13.3
s	1.8	1.2	317.0	557.7	1100.4	2.4	0.3	1.2	2.9	7.2	93.5	4.9	11.9
n	14	11	15	16	16	16	15	12	12	10	10	10	16
high	8.0	4.5	1732.0	1470.0	4070.0	8.8	1.3	4.8	10.1	22.1	348.5	18.1	46.1
low	1.5	0.5	298.0	20.0	2.8	0.5	0.0	0.0	0.4	0.0	10.4	1.9	1.8
KINNEMAN CREEK BED													
$\bar{x}$	5.0	---	507.0	484.0	325.8	12.0	0.1	2.5	1.0	7.1	51.6	2.5	6.6
s	4.2	---	237.8	369.4	200.3	16.7	0.1	1.3	---	5.4	12.0	1.6	1.1
n	2	---	4	9	6	6	2	2	1	5	2	2	2
high	8.0	---	837.0	1300.0	610.0	34.0	0.2	3.4	---	13.8	60.0	3.6	7.4
low	2.0	---	274.0	45.1	95.0	0.2	0.0	1.6	---	2.0	43.1	1.4	5.8
HAGEL BED													
$\bar{x}$	4.9	0.9	655.2	220.2	1072.7	1.2	0.4	0.8	2.8	16.9	159.6	6.0	8.9
s	6.1	0.9	399.2	156.4	1120.9	1.1	0.2	1.1	2.1	25.5	257.3	6.7	9.5
n	9	6	16	16	15	15	14	7	6	8	8	8	14
high	20.5	2.8	2040.0	580.0	3440.0	4.4	0.7	2.9	6.5	76.5	792.0	20.0	33.5
low	0.5	0.5	338.5	50.0	50.0	0.5	0.2	0.0	1.0	0.4	42.7	0.3	0.0
SAND 5m BELOW HAGEL BED													
$\bar{x}$	5.9	3.5	684.5	236.2	660.0	5.0	0.3	1.6	8.1	11.5	54.2	13.0	21.6
s	8.6	2.3	268.7	222.9	765.6	7.1	0.3	1.8	13.4	12.2	22.7	11.4	18.7
n	13	9	13	13	13	13	13	9	9	7	7	7	13
high	31.0	7.2	1055.9	630.0	2930.0	23.5	0.8	6.1	37.6	38.8	79.5	36.8	66.1
low	1.0	0.5	87.5	20.0	120.0	0.5	0.0	0.0	0.9	3.2	7.2	2.9	0.0
SILT 15m BELOW HAGEL BED													
$\bar{x}$	8.4	5.1	956.9	227.3	265.1	2.6	0.6	2.2	3.6	14.1	154.4	12.9	20.8
s	11.6	10.3	337.4	150.4	144.2	5.2	1.0	1.8	3.4	10.8	197.9	10.5	15.6
n	36	18	39	47	45	45	41	28	27	29	25	25	41
high	55.0	39.3	1592.0	640.0	770.0	25.2	4.6	6.1	14.0	39.0	758.0	52.6	83.9
low	1.0	0.5	203.0	30.0	49.0	0.2	0.0	0.0	0.0	0.9	31.6	2.1	0.2

C99, and C102, were beginning to show the influence of FGD waste leachate.

The groundwater in those piezometers is characterized by concentrations of sodium and sulfate that are greater than the average for those ions in unaffected spoil water by a factor of 2 to 3 (Table E-12). Sodium concentrations range from 493 to 1845 mg/L; sulfate concentrations range from 3575 to 4917 mg/L in FGD waste-affected groundwater. Total-dissolved-solids concentrations in the FGD waste-affected groundwater range from 6564 to 7872 mg/L. The average total-dissolved-solids concentrations in spoil water at the Center Mine is 3375 mg/L.

Iron concentrations in FGD waste-affected groundwater are generally less than in unaffected spoil water. Manganese concentrations show approximately the same range as unaffected spoil water. The concentrations of cadmium, lead, arsenic, and selenium in FGD waste-affected groundwater are within the same ranges as spoil water in unaffected areas. None of these ions exceed permissible limits for drinking water. The pH of groundwater in FGD waste-affected areas ranges from 6.15 to 7.30.

These data indicate, as suggested by laboratory studies, that the major potential impact on groundwater of FGD waste from the Milton R. Young plant is the generation of exceptionally high concentrations of sulfate and other major ions. The generation of these ions in solution, as previously discussed, is largely dependent upon the dissolution of soluble salts. Therefore, these impacts can be minimized by the design and selection of disposal sites which isolate the FGD waste from infiltrating water.

Fly Ash. Piezometers showing effects of fly ash leachate at the Center Mine include four (C133, C136, C139, and C140) in areas where the fly ash has been in place for approximately 12 months. In addition, one piezometer (C10) is adjacent to an area where fly ash was buried in the spoil approximarely 6 to 7 years ago (Table E-12).

The groundwater in these piezometers is characterized by exceptionally high concentrations of sodium and sulfate. Sodium concentrations range from 953 to 16,947 mg/L; sulfate concentrations range from 3213 to 36,820 mg/L. Total-dissolved-solids concentrations in fly ash-affected groundwater range from 5425 to 52,650 mg/L.

Iron and manganese concentrations vary considerably, ranging from 4 to 2590 mg/L and 10 to 6500 mg/L respectively. Cadmium concentrations in fly ash-affected groundwater are within the same range as unaffected spoils. Lead concentrations generally show a significant increase over concentrations in unaffected spoil, ranging from 8 to 236 µg/L.

Arsenic and selenium concentrations show extreme variability. Arsenic ranges from <1 to 613 µg/L in fly ash-affected groundwater. Selenium ranges from <1 to 800 µg/L. Noteworthy is the fact that both arsenic and selenium show highest concentrations in groundwater having high pH values. Molybdenum is extremely high in some of these samples, ranging from 218 to 38,460 µg/L. Molybdenum concentrations in lignite and sand aquifers in western North Dakota generally range from 10 to 30 µg/L. The pH in fly ash-affected groundwater at the Center Mine ranges from 6.95 to 12.1.

Table E-12. Groundwater analyses from piezometers in area of FGD waste and fly ash disposal, Center Mine.

Piezometer No.	Date	Field Temp.	Field pH	Field Cond.	TDS	Alk.	Ca	Mg	Na	K	HCO$_3$	SO$_4$	Cl	NO$_3$	F
					←					mg/L					→
Piezometers Showing Influence of Fly Ash FGD Waste															
C 94	03-27-80	8.0	6.30	>8,000	7,872	163.4	195.3	615	900	55.0	199.4	4,917	10.7	-	<0.1
C 94	06-09-80	11.0	7.30	13,600	7,772	191	307	262	493	32	233.0	3,572	-	-	-
C 102	06-09-80	14.0	7.20	12,400	7,198	633	186	105	1,845	24	772.3	4,343	-	-	-
C 99	03-29-80	9.5	6.15	8,000	7,220	553.4	215.5	530	960	24.2	675.2	4,111	22.0	-	0.73
C 99	06-09-80	14.0	7.25	10,000	6,564	645	393	408	1,050	24	786.9	3,811	-	-	-
Piezometers Showing Influence of Fly Ash															
C 10	11-10-78	6.0	12.10	>8,000	5,425	485	32.8	0.2	1,550	198.4	591.7	3,213	27.0	0.60	1.4
C 10	07-06-78	11.5	11.74	>8,000	5,548	715.2	28.2	0.1	1,340	9.7	872.5	3,015.5	19.8	1.13	1.7
C 10	02-24-79	4.5	11.85	>8,000	5,715	500	30.8	1.3	1,517	198.3	610.0	3,607.3	26.5	0.13	1.65
C 133	06-19-80	15.0	8.75	21,600	12,270	182.7	780.7	39.9	3,364	500	209.3	8,893	11.9	0.15	0.16
C 136	05-20-80	13.0	7.80	29,000	12,420	364.1	240	123.0	5,119	280	432.3	9,265	13.0	0.10	0.49
C 136	07-28-80	13.2	7.9	6,500	10,690	381.6	220.4	131.9	2,963	287.6	460.3	6,723.2	11.3	0.21	0.66
C 139	05-20-80	13.0	6.95	13,600	6,960	569	515	312.9	1,303	75	688.1	4,357	9.0	0.40	0.23
C 139	07-28-80	12	7.25	7,800	6,720	578.8	524.7	292.8	953	35.4	698.6	3,428	9.8	0.24	0.32
C 140	06-19-80	14.5	11.55	99,200	52,650	534.9	130.4	20.6	13,573	2930	24.5	36,820	74.9	0.34	0.84
C 140	07-28-80	17.0	11.62	>8,000	50,110	684.6	97.7	19.6	16,947	-	16.7	31,045	57.7	0.23	2.34

Position of Screened Interval

C 94	In spoils, offset from FGD waste approximately 10 m
C 99	In base of spoils, 11 m below FGD waste
C 102	In base of spoils, slight offset from FGD waste
C 10	In base of spoils, offset from fly ash unknown distance
C 133	In base of spoils, offset 20-25 m and 10 m below fly ash
C 136	In base of spoils, 11 m below fly ash
C 139	In base of spoils, 7.5 m below fly ash
C 140	In spoils, immediately below fly ash

Table E-12. (continued)

Piezometer No.	Fe	Mn	Cd	Hg	Se	As	Pb	Mo
	←				µg/L			→
Piezometers Showing Influence of Fly Ash FGD Waste								
C 94	130	4,410	1.8	<0.3	<2	3.0	-	-
C 94	20	-	<1	<0.3	<2	<2	7.3	-
C 102	90	-	3.3	<0.3	5.6	<2	29	-
C 99	50	1,740	1.4	0.6	2	2	-	-
C 99	250	-	<1	<0.3	<2	<2	7.4	-
Piezometers Showing Influence of Fly Ash								
C 10	30	24	3.6	0.7	13.6	204.6	58.0	-
C 10	20	10	<1	0.8	3.8	171.8	33.1	-
C 10	110	20	4.7	0.3	8.2	97.8	-	-
C 133	140.7	-	3.75	-	-	13.3	7.67	17,019
C 136	4	-	0.82	-	-	22.6	236.0	4,500
C 136	308	495	0.24	-	0.56	35.3	28.1	5,466
C 139	2,080	-	0.39	-	-	0.3	60.0	640
C 139	2,590	6,500	0.9	-	0.56	6.2	16.1	218
C 140	21.8	-	0.78	-	800	550	34.1	23,700
C 140	1,376	271	4.3	-	760	613	-	38,460

These data indicate that fly ash from the Milton R. Young plant can potentially cause groundwater to acquire exceptionally high concentrations of sulfate and other major ions. In addition, the fly ash has the potential to severely degrade groundwater with respect to arsenic selenium, molybdenun, and possibly lead. Proper disposal of fly ash is therefore of critical concern. The selection and design of disposal sites for fly ash will require extreme caution and a detailed knowledge of the hydrogeologic conditions in proposed disposal areas.

SUMMARY OF CONCLUSIONS

Chemical analyses of absorber tower liquor, supernatant solution from transportation vessels and from batch shaker tests, pore water extracted by squeezing of FGD waste samples, and effluent from column experiments all indicate that waters in contact with FGD waste from the Milton R. Young power plant are characterized by sulfate concentrations sufficiently high to make the water unfit for drinking and for most agricultural uses. These waters have pH values that are not much above the pH of natural groundwater in the Center area. Water in contact with FGD waste that has not been previously leached acquires fluoride concentrations that are commonly greater by a factor of 2 to 4 than the limit specified for drinking water. Lead is generally greater than the drinking water limit by a factor of 1.5 to 3, and cadmium by a factor of 1.5 to 5. Insufficient data are available to draw general conclusions for selenium; preliminary results suggest that this element will exceed the drinking water limit by a factor less than 2. When water continuously passes through FGD waste, the concentrations of fluoride, lead, and cadmium generally decline to levels near or below the drinking water limits but sulfate remains above the limit by a factor of 5 to 10.

Laboratory studies indicate that water in contact with fly ash becomes very alkaline with pH generally between 11 and 13, and commonly acquires concentrations of arsenic and selenium that exceed the drinking water limits by factors as large as 15 and 35 respectively. In terms of major ion composition, the fly ash water should be similar to FGD waste water in that it should be characterized by high concentrations of sulfate, sodium, magnesium, and calcium.

The natural groundwater in coal-mining areas in western North Dakota commonly has sulfate concentrations that exceed the recommended limit for drinking water. Groundwater in spoil in areas of reclaimed land commonly has exceptionally high sulfate concentrations and therefore is sometimes unsuitable for domestic or agricultural use. FGD waste and fly ash can cause exceptional changes in the quality of groundwater because of the input of toxic constituents such as As, Se, F, Pb, and Cd to groundwater and in this regard fly ash is a considerably greater hazard to groundwater than FGD waste.

Although the fly ash and FGD waste contain about the same quantities of arsenic and selenium, only the fly ash imparts high concentrations of these elements to water. This is attributed to the effect of pH; laboratory experiments indicate that the high pH caused by the fly ash may be responsible for the high arsenic and selenium concentrations. At pH levels in the normal groundwater range, the concentrations of these elements are rarely high. Although it is known that high aresnic and selenium concentrations occur at high pH and rarely at lower pH, the specific chemical effect of pH is not understood at present. It appears that desorption of these elements from the surfaces of solids caused by the increase in hydroxyl ions may be a major factor. The fact that water in contact with fly ash attains a very high pH and water in contact with FGD waste does not is due to the relatively higher content of oxides of calcium, magnesium, and sodium in the fly ash. The oxides undergo spontaneous hydrolysis to produce a large deficiency of hydrogen ions and thus the high pH.

Calculations of saturation indices indicate that sulfate concentrations of water in contact with fly ash and FGD waste are limited by the solubility of gypsum and that gypsum solubility is the main factor limiting the levels to which total dissolved solids and electrical conductance can rise. Although pore waters extracted from and the effluent from FGD waste columns are at or close to equilibrium with respect to gypsum, the concentration of sulfate, calcium, magnesium, sodium, and total dissolved solids vary considerably. The equilibrium concentrations of calcium and sulfate can vary, because sodium and magnesium form pairs and complexes with sulfate that can comprise a large percentage of the total sulfate when sodium and magnesium concentrations are high. The amounts of sodium and magnesium in soluble form are therefore important controls on the levels to which sulfate, calcium, and total dissolved solids can rise. As water passes through FGD waste, the leachable sodium and magnesium are removed more rapidly than calcium and sulfate and therefore the influence of ion pairing and complexing decreases with a corresponding decrease in the equilibrium sulfate concentrations to values generally in the range of 1400 to 2000 mg/L.

The ability of fly ash and scrubber waste to cause groundwater to acquire exceptionally high concentrations of sulfate and major cations was confirmed by the results of sampling of piezometers installed in spoil at the Center site where these wastes have been buried. The occurrence of groundwater with pH values in the range of 11 to 13 and high concentrations of arsenic selenium, and molybdenum provided confirmation of the conclusions that fly ash has the potential to cause severe degradation of groundwater in reclaimed land. Arsenic and selenium in high pH groundwater are contaminants with exceptionally adverse hydrogeologic characteristics because they exist in solution as very soluble anions that may not undergo much geochemical attenuation as they are transported along groundwater flow paths. The mobility of these anionic contaminants in groundwater in spoil and adjacent zones is a subject of current research.

Although the primary purpose of fly-ash-type flue gas desulfurization systems is to reduce atmospheric contamination, the results of this study show that a secondary benefit of this method of flue-gas processing is the conversion of fly ash from a form that can cause groundwater to acquire severe toxicity because of high aresenic and selenium levels to a waste form that causes increased sulfate concentrations but generally no significant increases in the more toxic elements.

Burial of FGD waste in mined areas offers an effective means of disposing of this waste, providing that the waste is placed in favorable locations in the mined area and provided that the selective placement of the waste and spoil is accomplished with appropriate consideration for the hydrologic and geochemical nature of the system.

Placement of these wastes in V-notch settings appears to be highly preferable to pit bottom disposal in most areas. V-notch areas are commonly above the postmining water table, and thus offer much less opportunity for the dissolution and leaching of soluble salts present in these waste products. Ongoing research will better evaluate the suitability of various postmining landscape positions for the disposal of fly ash and fly ash FGD waste.

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